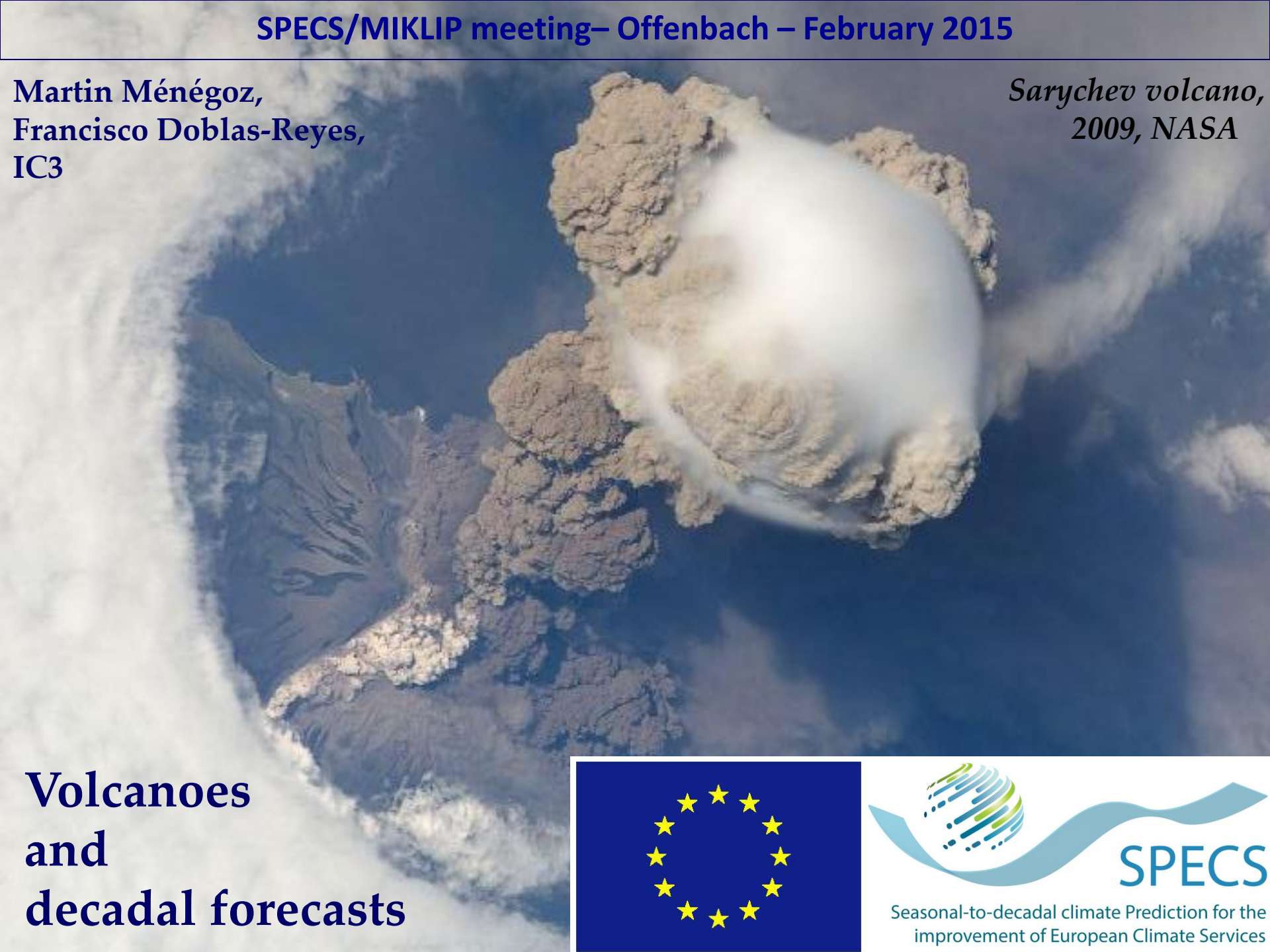


Martin Ménégoz,  
Francisco Doblas-Reyes,  
IC3

*Sarychev volcano,  
2009, NASA*



**Volcanoes  
and  
decadal forecasts**







## Climate response to volcanoes

---

- Major eruptions bring large amounts (Tg) of particles in the stratosphere.
- Last large eruptions: Agung (1963), El Chichon (1982) and Pinatubo (1991).
- Global temperature decrease of  $0.1-0.3^{\circ}\text{C}$ , atmospheric impacts noticeable during 5 years, and potential effects on ocean circulation during 10-20 years.
- Summer cooling, winter warming (?) in some parts of the NH. Climate impact difficult to understand, especially in forecasts!

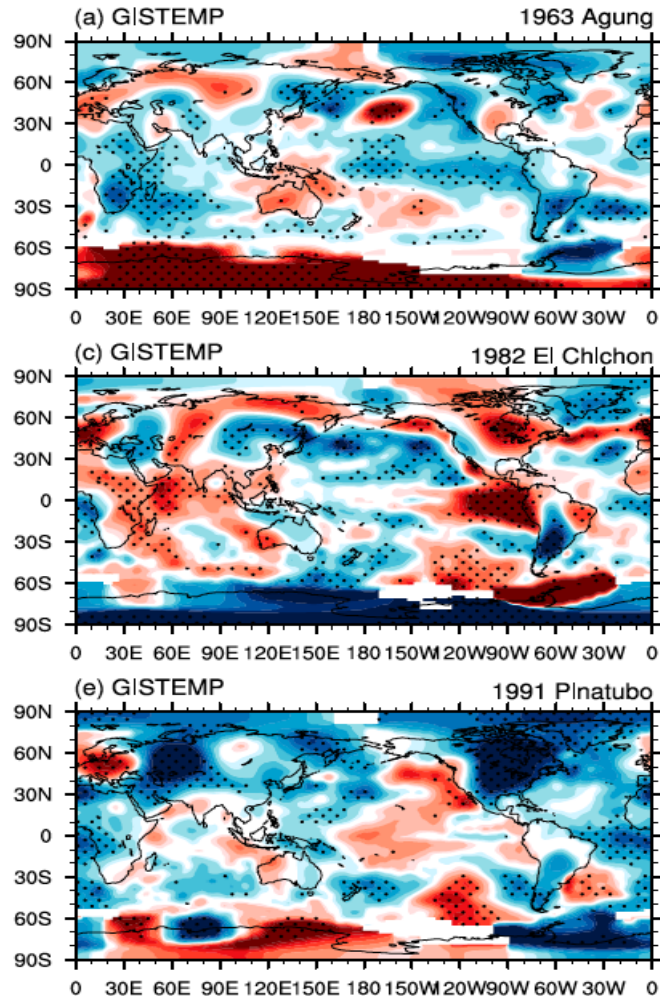
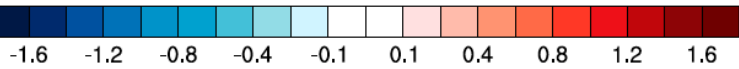
- 
- Climate response to volcanoes
  - Forecasts, anomalies and skills
  - Large eruptions and the AMO
  - Conclusions

- 
- **Climate response to volcanoes**
  - Forecasts, anomalies and skills
  - Large eruptions and the AMO
  - Conclusions



## Climate response to volcanoes

→ High climate natural variability can overwhelm the volcanic signal

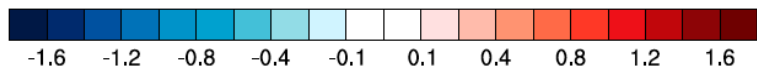


*Surface temperature anomalies (°C) the first summer after eruptions (Man et al., 2014).*

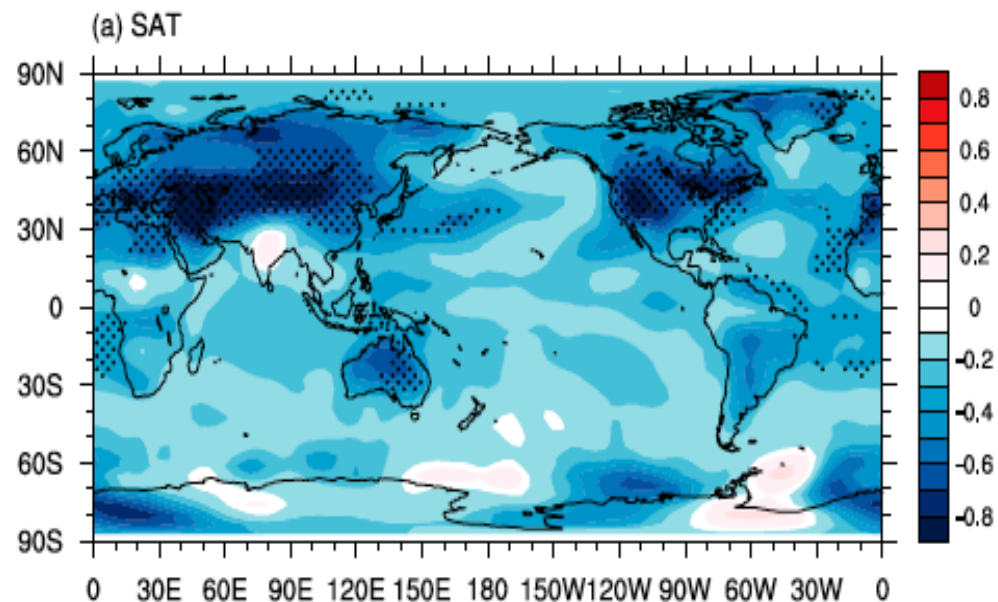
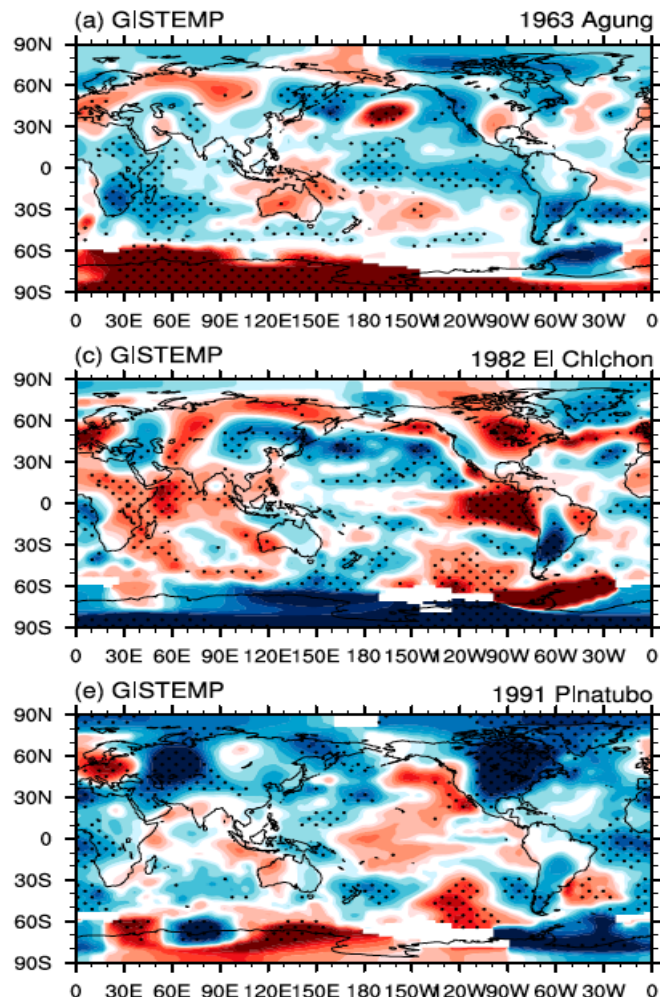




## Climate response to volcanoes



→ High climate natural variability can overwhelm the volcanic signal



*Composite of the surface temperature the first summer after the 21 major eruptions simulated over the last 1000 years (Man et al., 2014).*

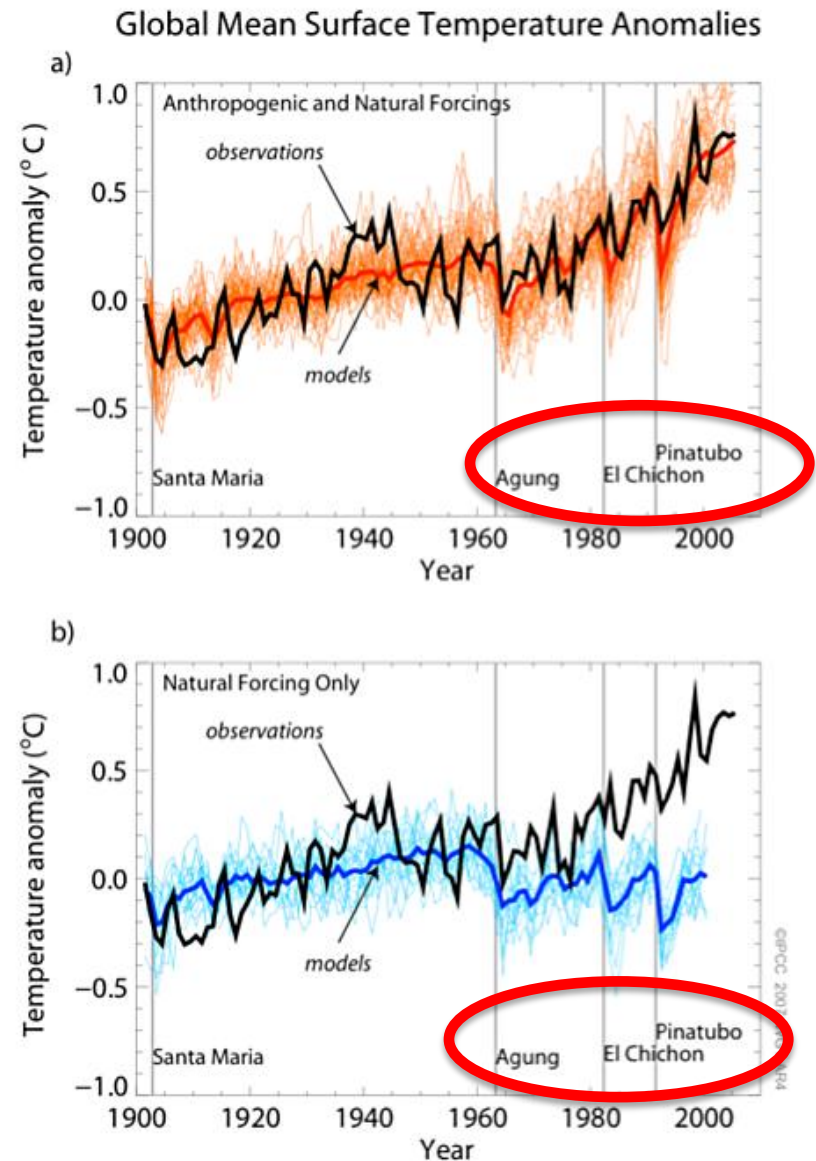
*Surface temperature anomalies (°C) the first summer after eruptions (Man et al., 2014).*



## Global surface temperature response

→ Signature of large eruptions seems to be obvious

*Global temperature anomaly over the XXth century (IPCC, AR4)*

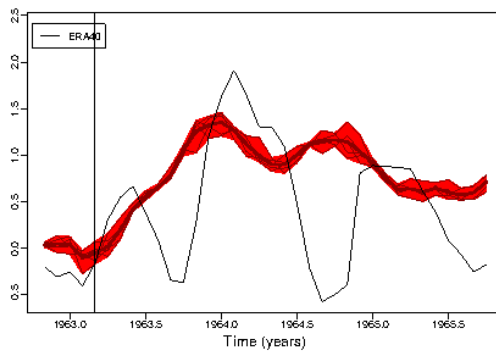




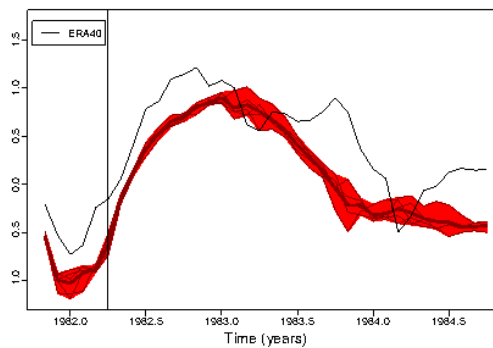
## EC-Earth experiments

→ CMIP5 Decadal hindcasts and sensitivity forecasts without volcanic forcing during large eruptions, temperature in the stratosphere:

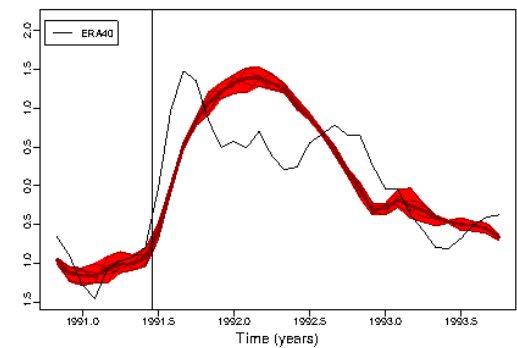
TA50 global anomalies with volcanoes forcing (forecast year 1-3)



Agung

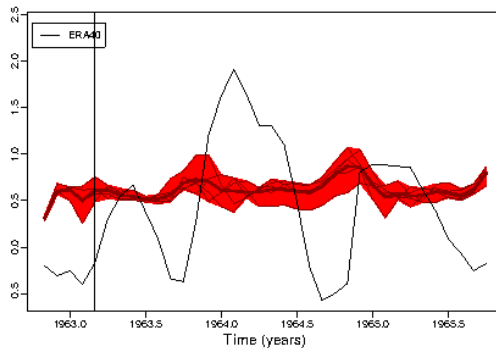


El Chichon

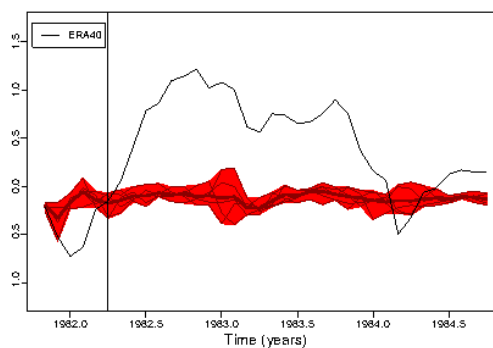


Pinatubo

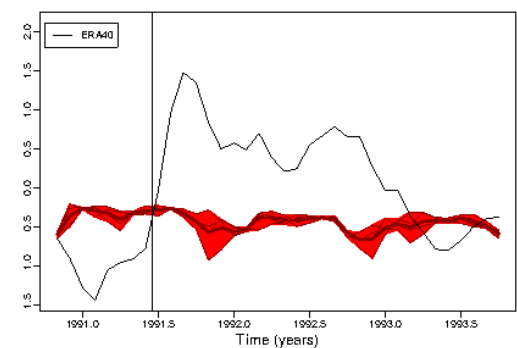
TA50 global anomalies without volcanoes forcing



Agung



El Chichon



Pinatubo

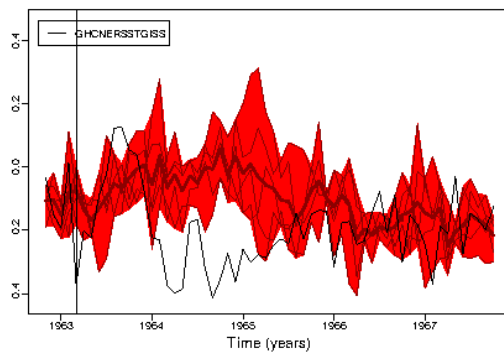




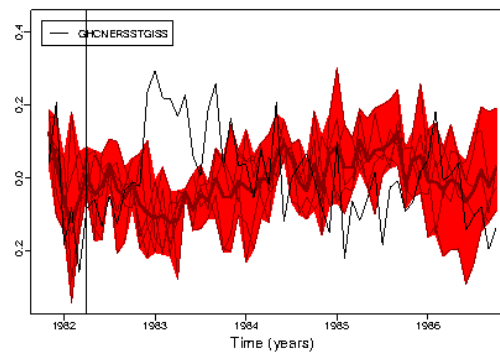
## EC-Earth experiments

→ CMIP5 Decadal hindcasts and sensitivity forecasts without volcanic forcing during large eruptions, temperature in the troposphere:

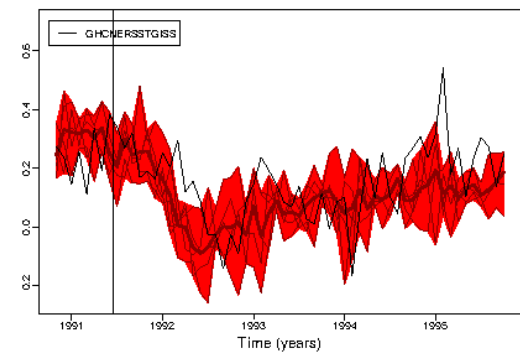
TAS global anomalies with volcanoes forcing (forecast year 1-5)



Agung

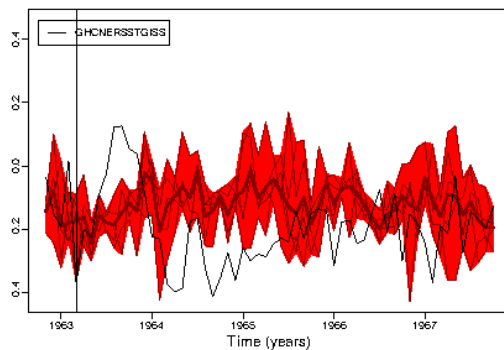


El Chichon

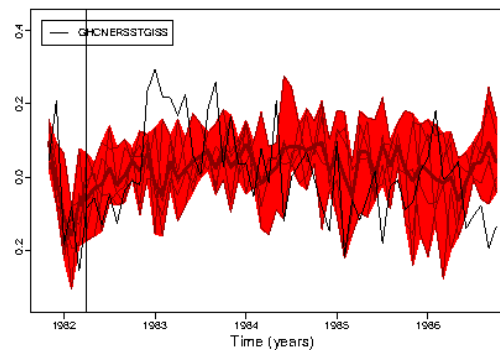


Pinatubo

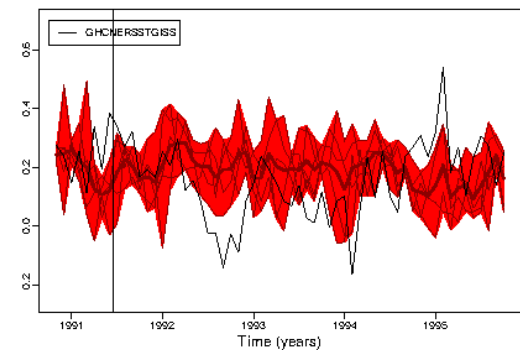
TAS global anomalies without volcanoes forcing



Agung



El Chichon

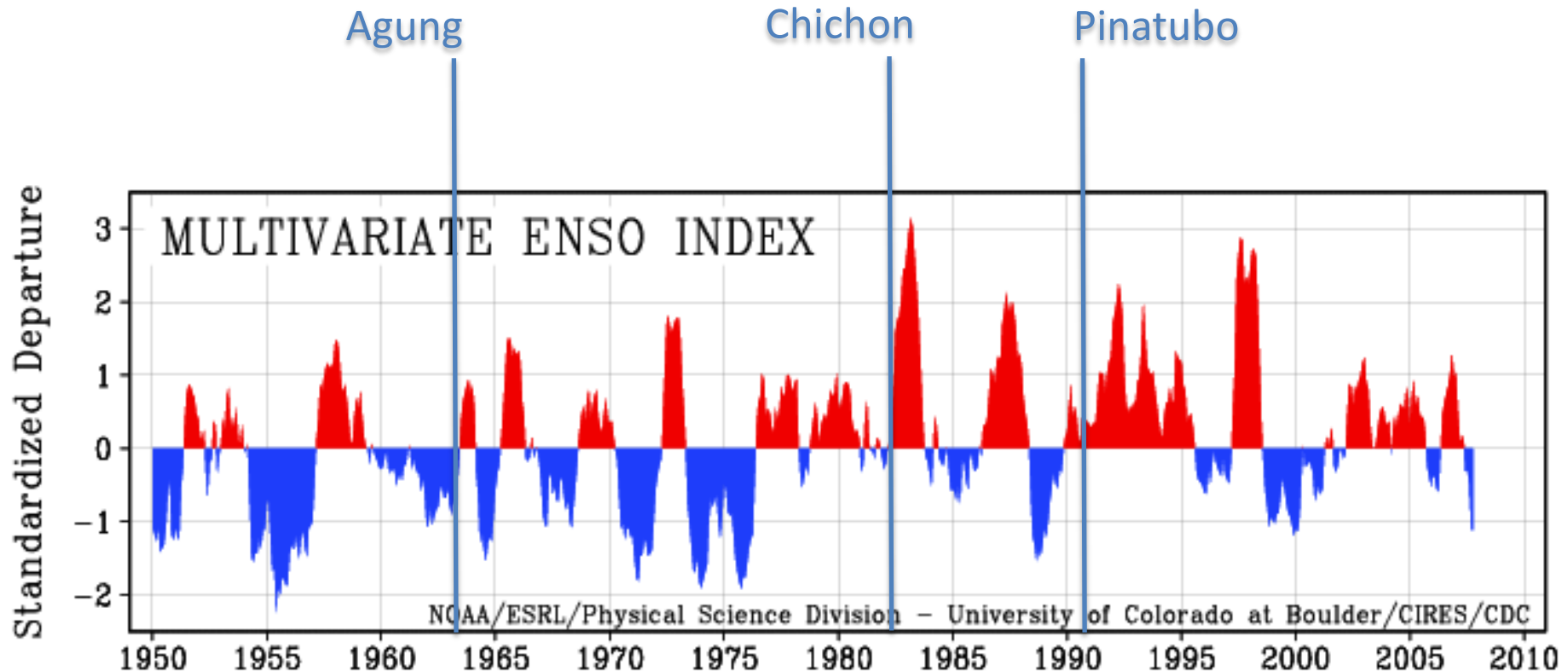


Pinatubo



## Global surface temperature response

→ Mixing between ENSO and volcanoes !



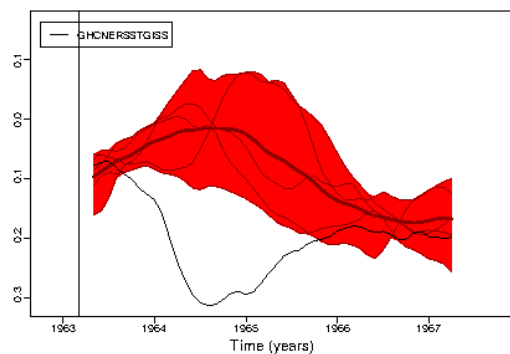
*ENSO INDEX (NOAA)*



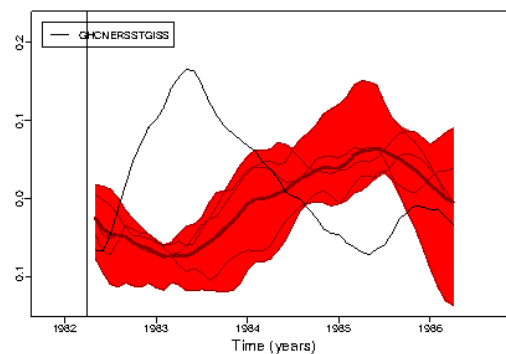
## EC-Earth experiments

→ With annual averages, the impact of Agung and Pinatubo on T global is obvious, but el Chichon eruption is masked by a Niño event!

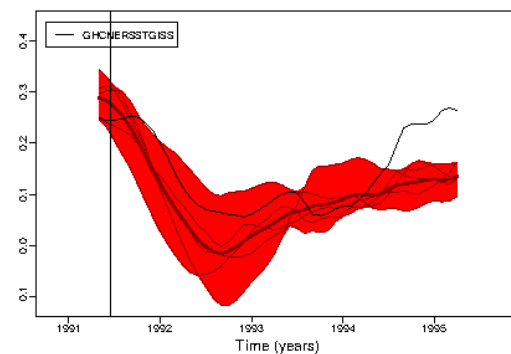
TAS global smoothed anomalies with volcanoes forcing (forecast year 1-5)



Agung

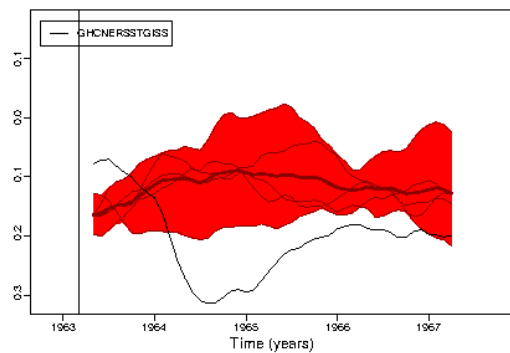


El Chichon

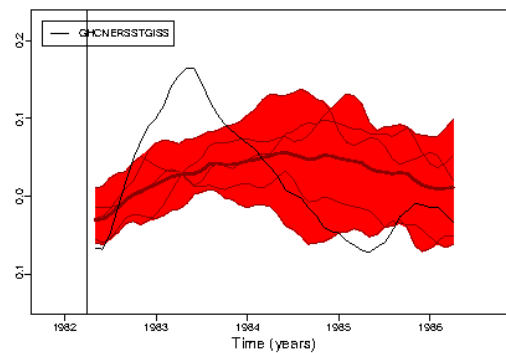


Pinatubo

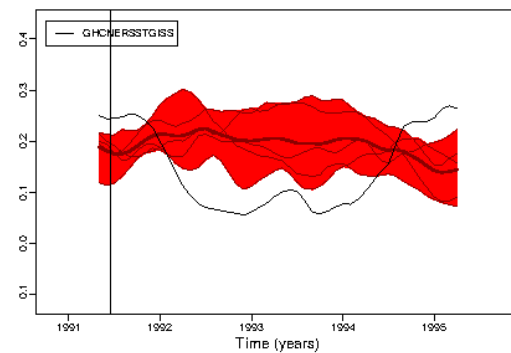
TAS global smoothed anomalies without volcanoes forcing



Agung



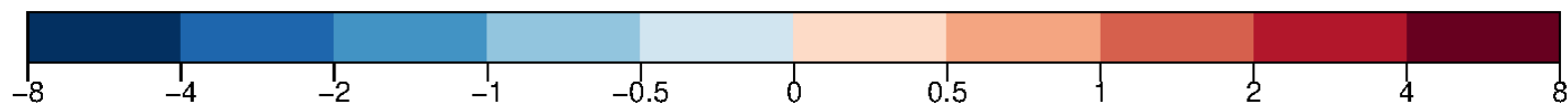
El Chichon



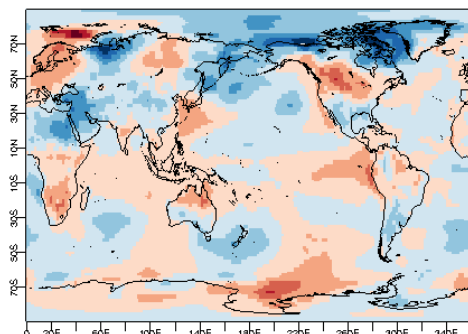
Pinatubo



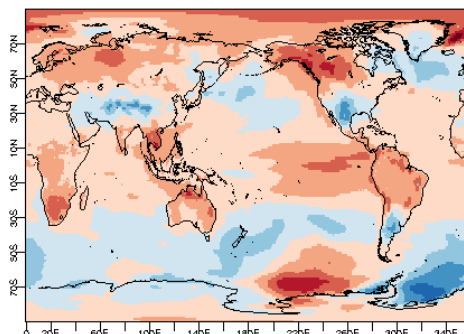
## Modelled climate response to volcanoes: temperature anomalies ( $^{\circ}\text{C}$ )



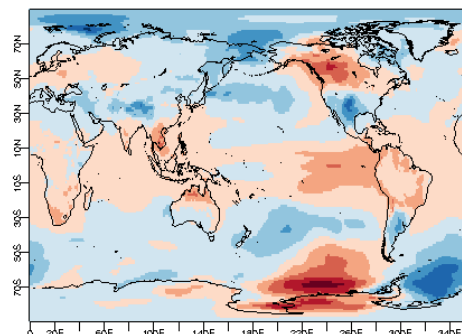
Year1



obs

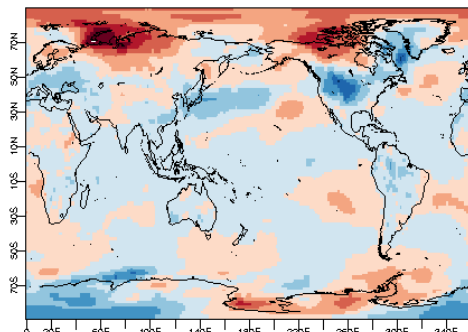


only initialization

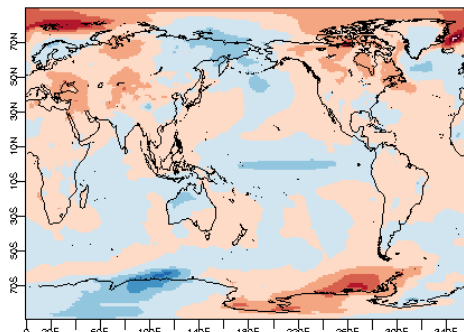


initialisation and volcanoes forcing

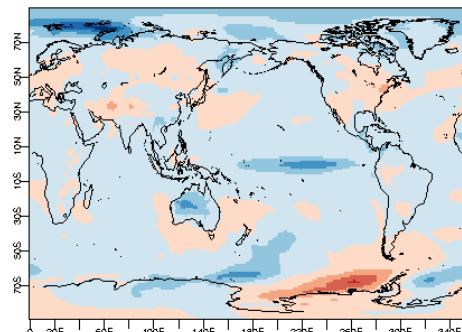
Year2



obs



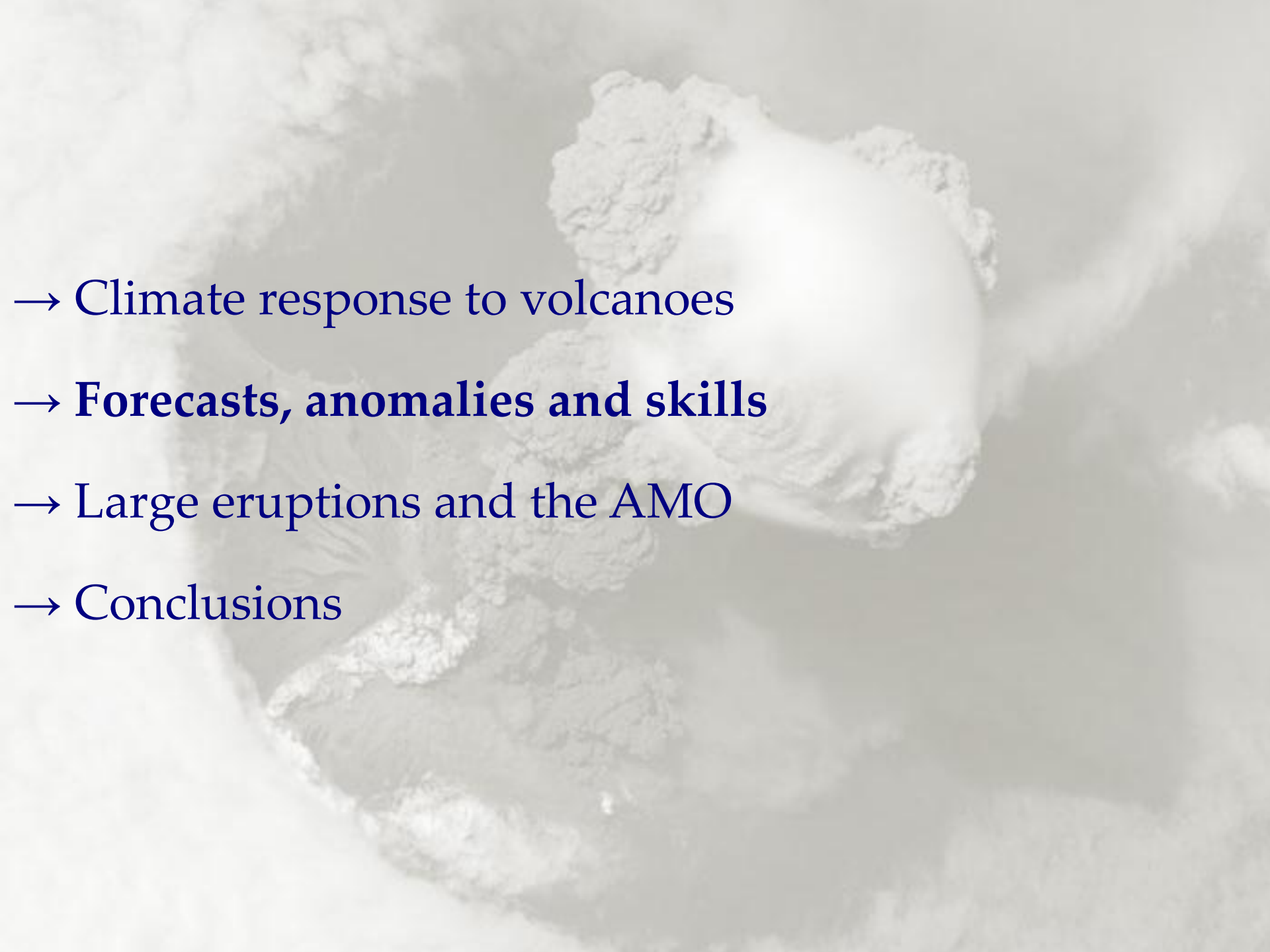
only initialization



initialisation and volcanoes forcing

→ 1 observation versus (5 members x 3 startdates = 15) simulations

→ Volcanic signal => significant cooling, but partly masked by ENSO !

- 
- Climate response to volcanoes
  - **Forecasts, anomalies and skills**
  - Large eruptions and the AMO
  - Conclusions

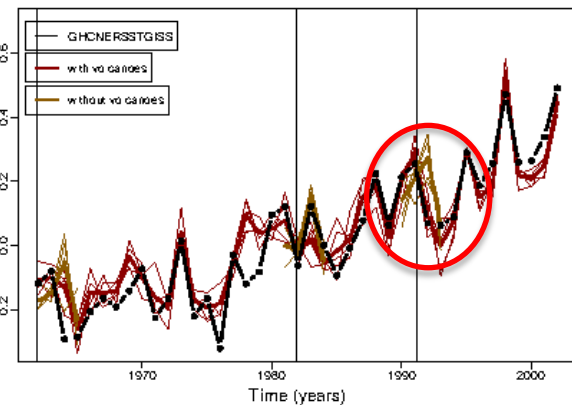




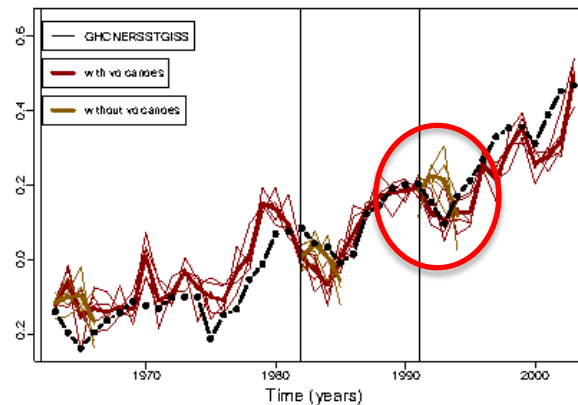
## Computing the skills of hindcasts over the last decades

→ Computing the anomalies

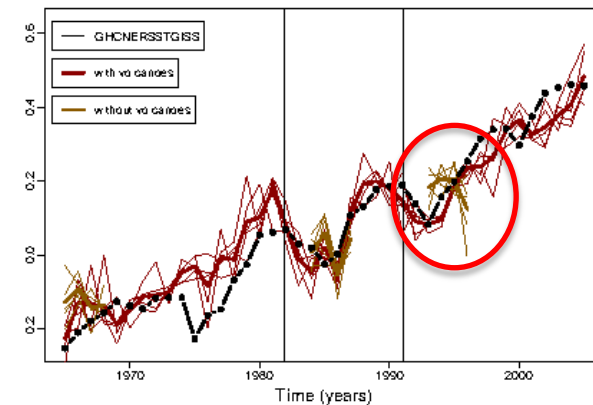
### TAS global anomalies



forecast year 1



forecast years 1-3



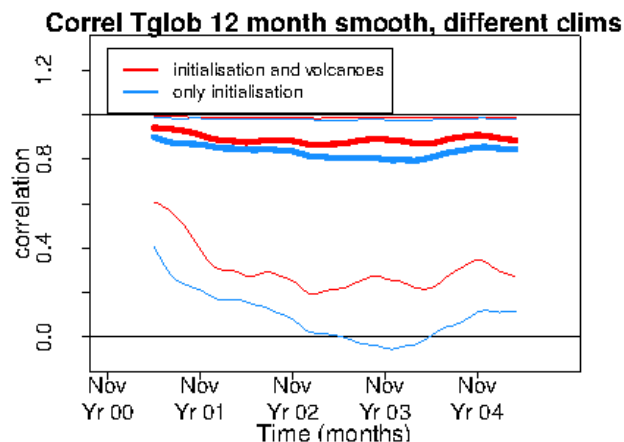
forecast years 3-5

**Observation**  
**With volcanoes**  
**Without volcanoes**

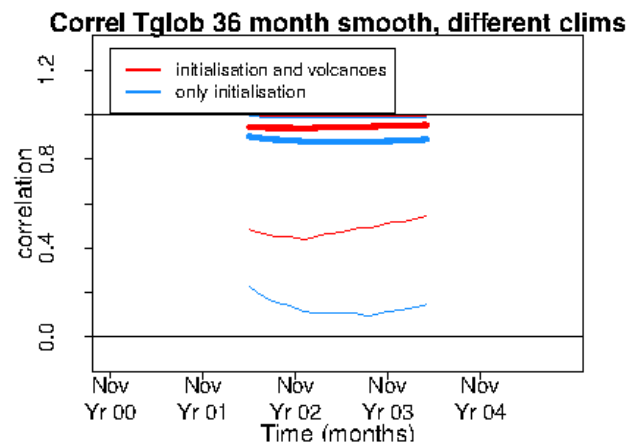


# Computing the skills of hindcasts over the last decades

## Correlation for global TAS anomalies

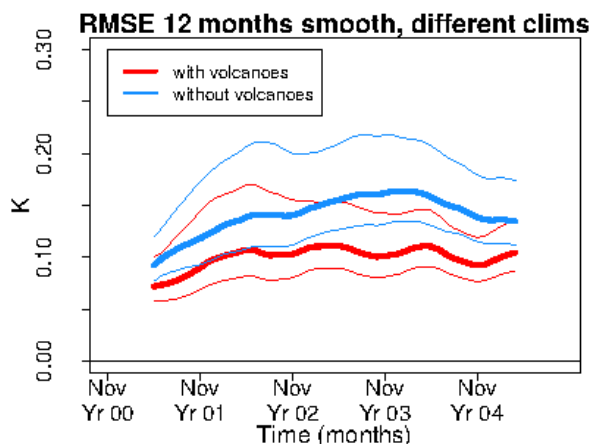


1-year average

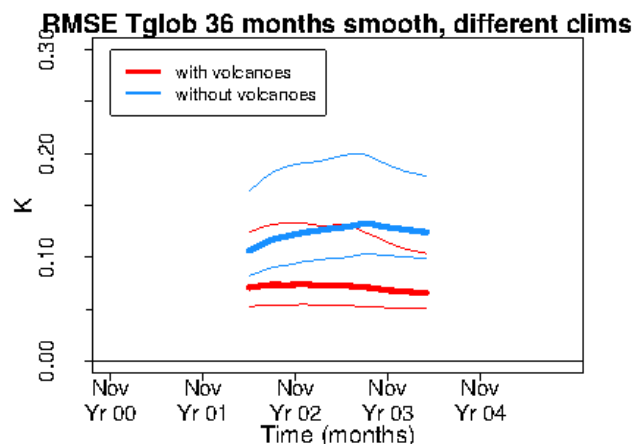


3-year average

## RMSE for global TAS anomalies



1-year average



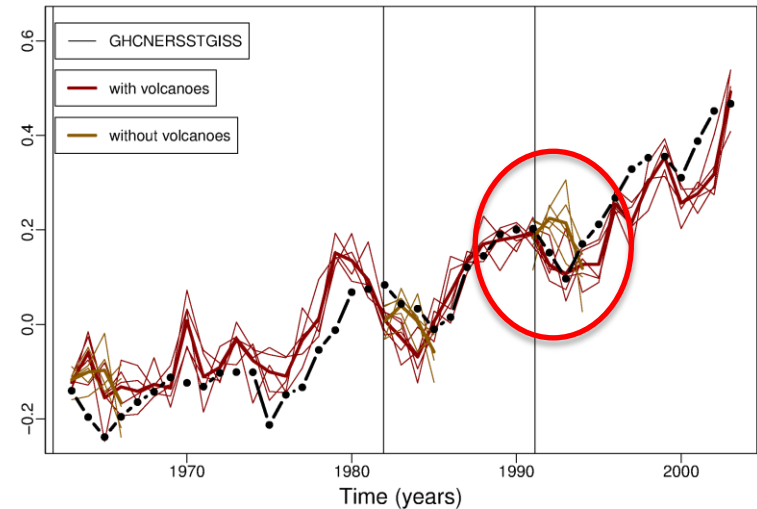
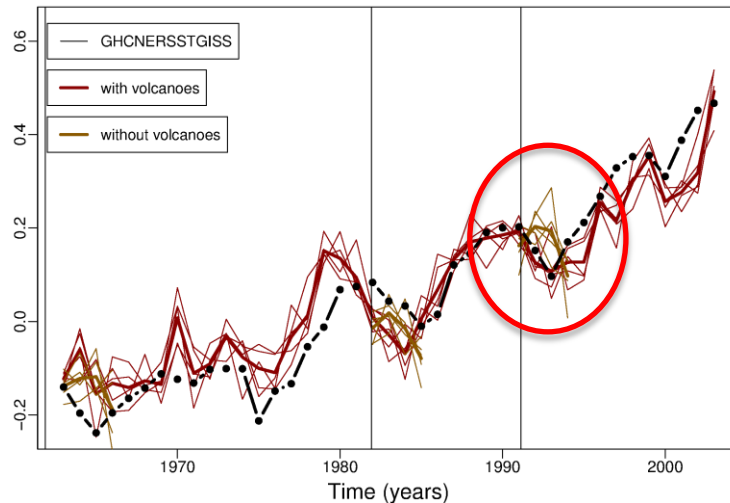
3-year average



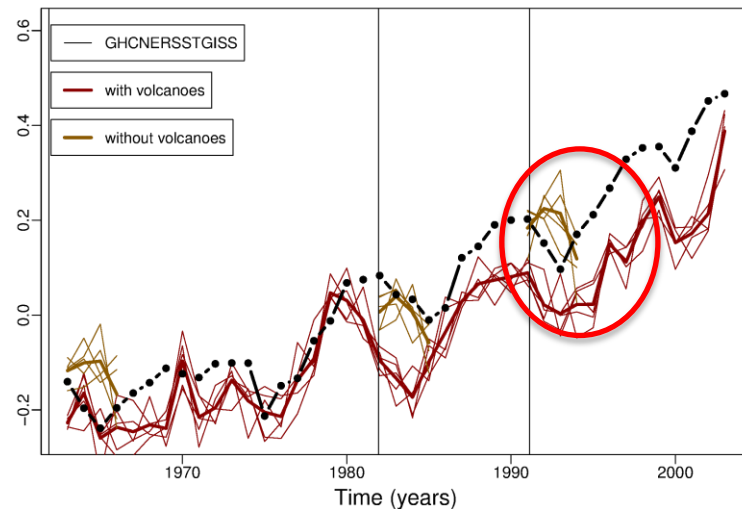
## Skills of hindcasts over the last decades

→ How computing climatology for the anomalies ?

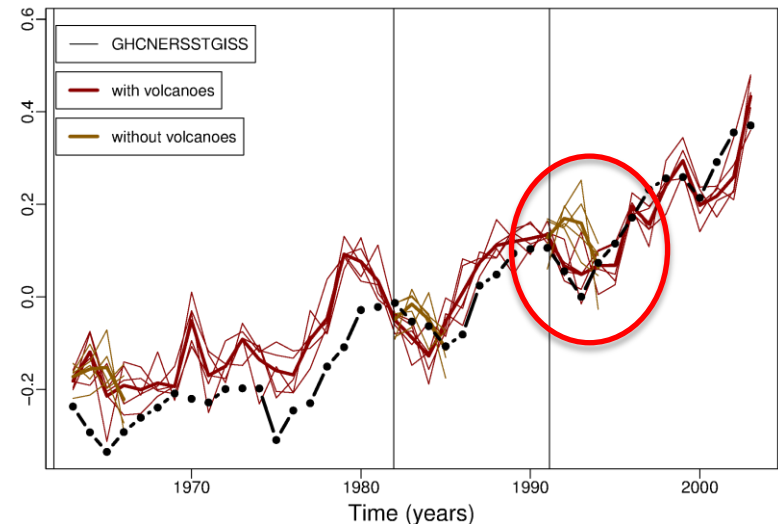
— Observation  
— With volcanoes  
— Without volcanoes



*Over the years with eruptions (12 stardates) Each simulation with its own climatology*



*Climatologies without volcanoes*

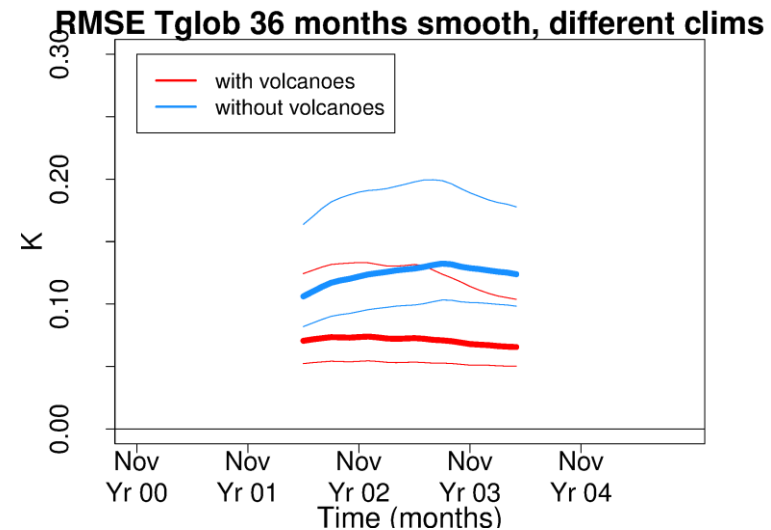
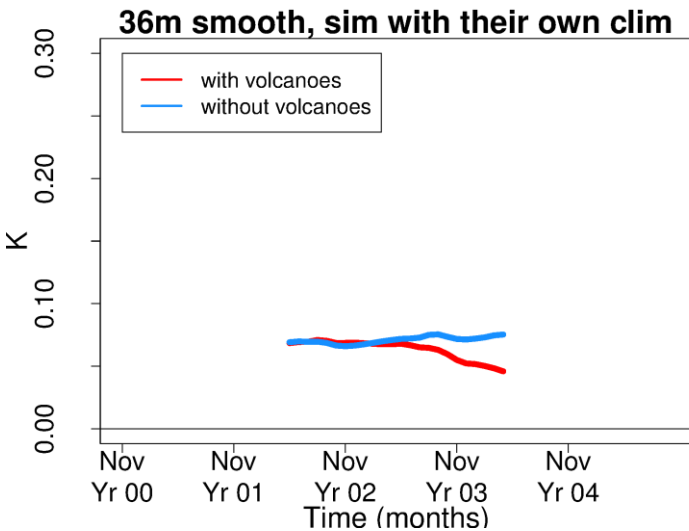


*Only over 1971-2001*



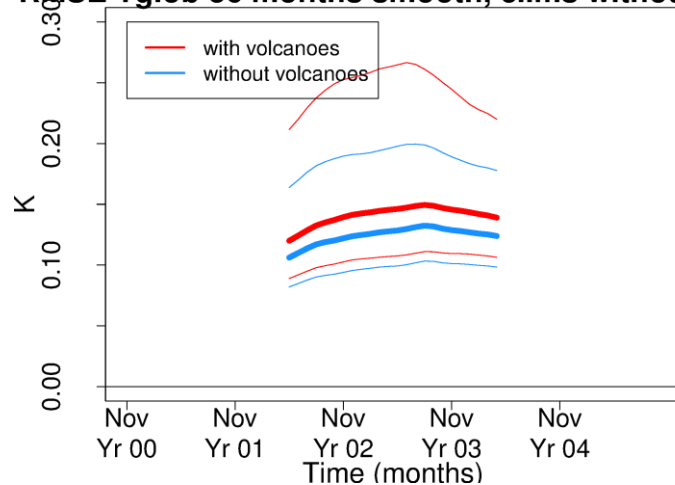
## Computing the skills of hindcasts over the last decades

### → RMSE



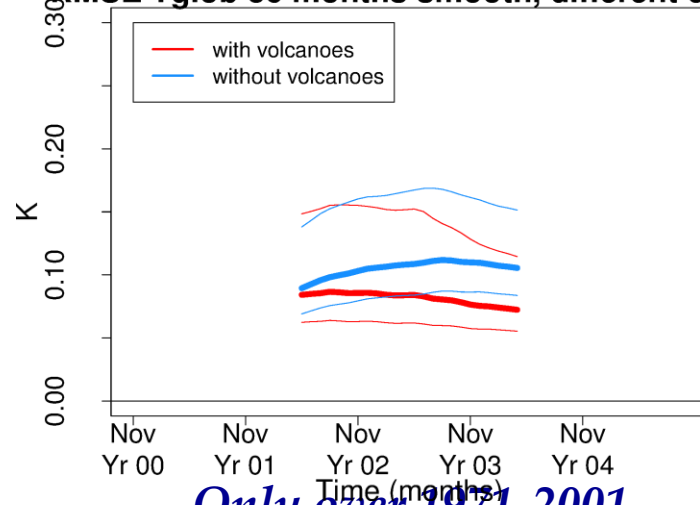
*Over the years with volcanoes (12 stardates) Each simulation with its own climatology*

**RMSE Tglob 36 months smooth, clims without vol**



*Climatologies without volcanoes*

**RMSE Tglob 36 months smooth, different clims**

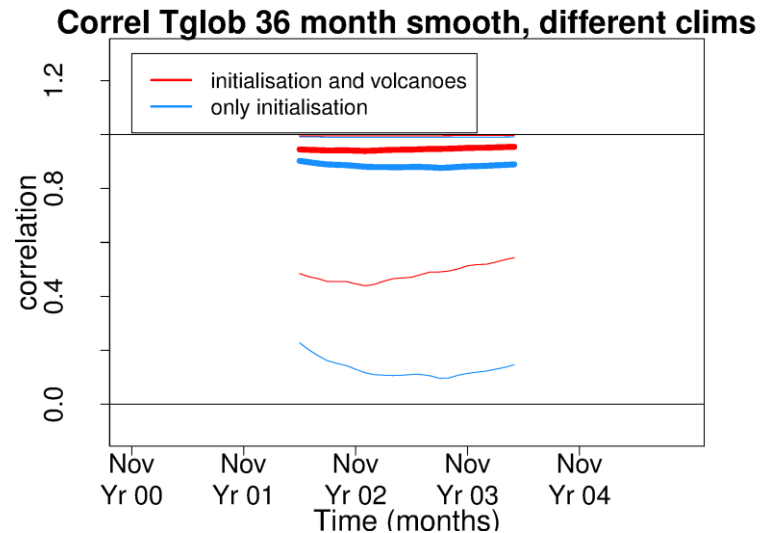
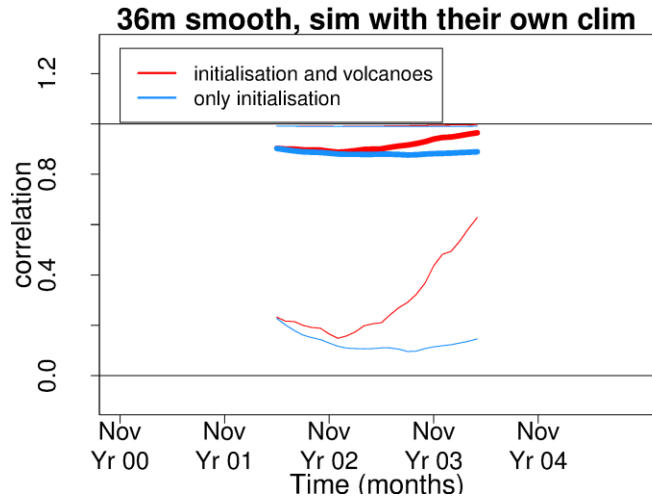


*Only over 1971-2001*



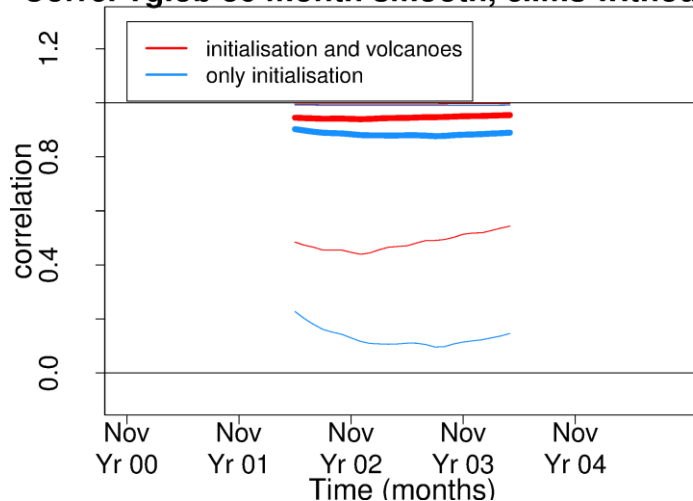
# Computing the skills of hindcasts over the last decades

## → Correlations



*Over the years with eruptions (12 stardates)*

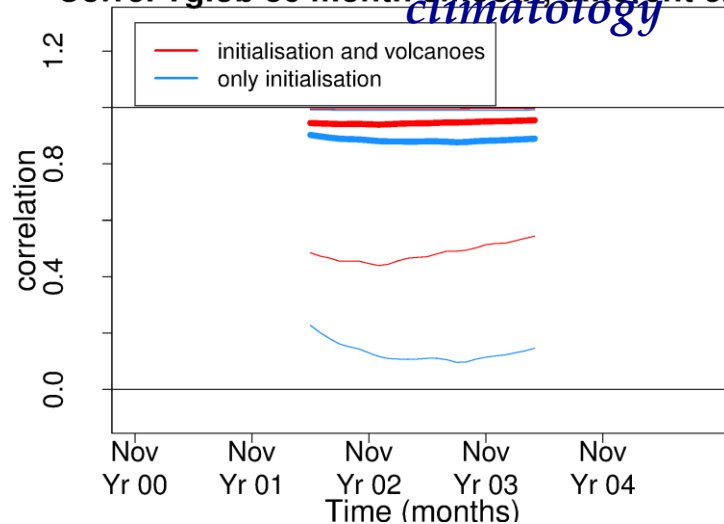
**Correl Tglob 36 month smooth, clims without vol**



*Climatologies without volcanoes*

*Each simulation with its own climatology*

**Correl Tglob 36 month smooth, different clims**

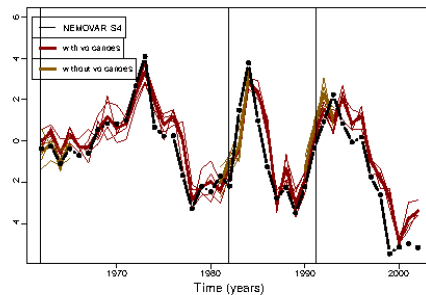


*Over 1961-2001*

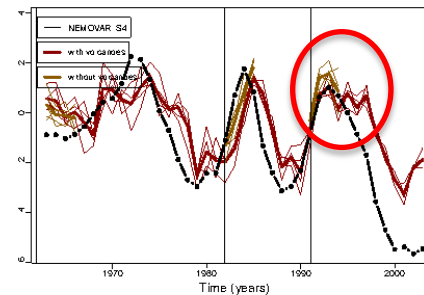




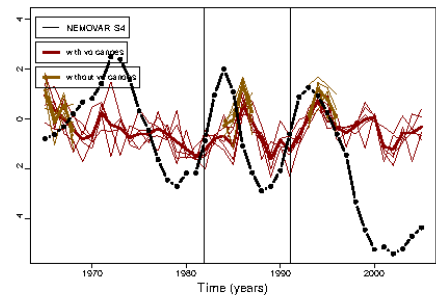
# Skills for the AMOC



forecast year 1



forecast years 1-3



forecast years 3-5

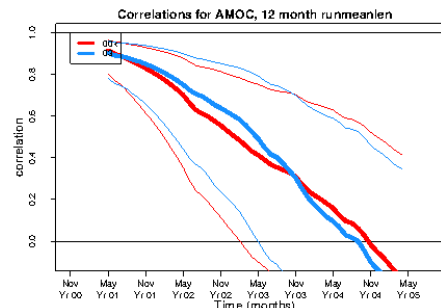
## Correlation for global AMOC anomalies



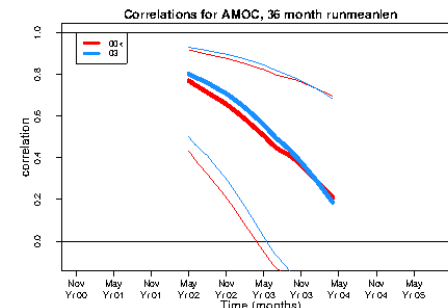
*Observation*

*With volcanoes*

*Without volcanoes*

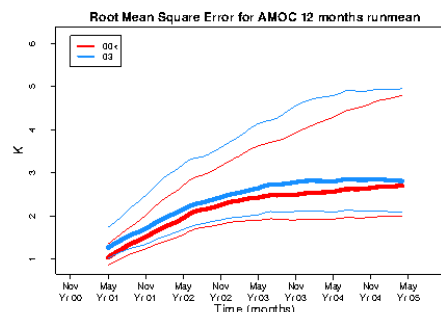


1-year average

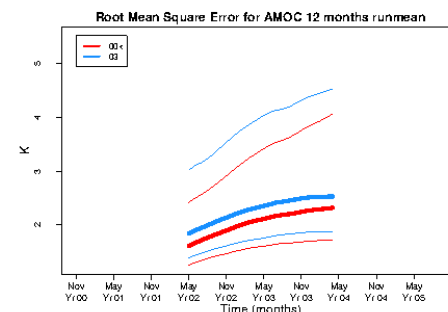


3-year average

## RMSE for global AMOC anomalies



1-year average

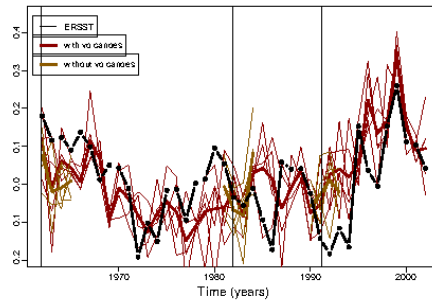


3-year average

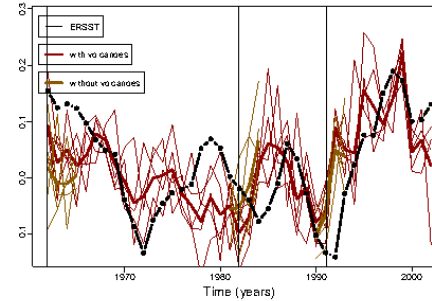
*(With mixed  
climatology only for  
the experiment  
without volcanoes)*



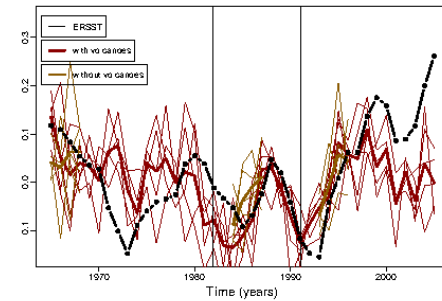
# Skills for the AMO



forecast year 1



forecast years 1-3



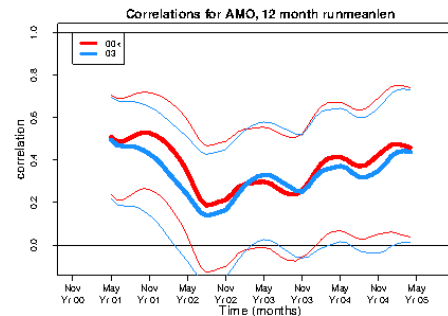
forecast years 3-5

## Correlation for global AMO anomalies

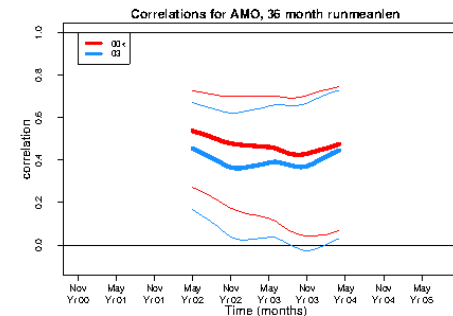
Observation

With volcanoes

Without volcanoes

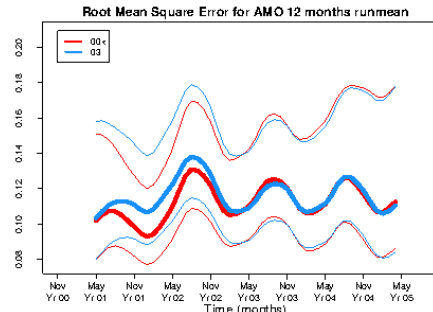


1-year average

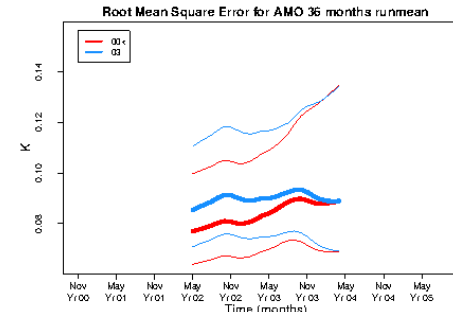


3-year average

## RMSE for global AMO anomalies




1-year average



3-year average

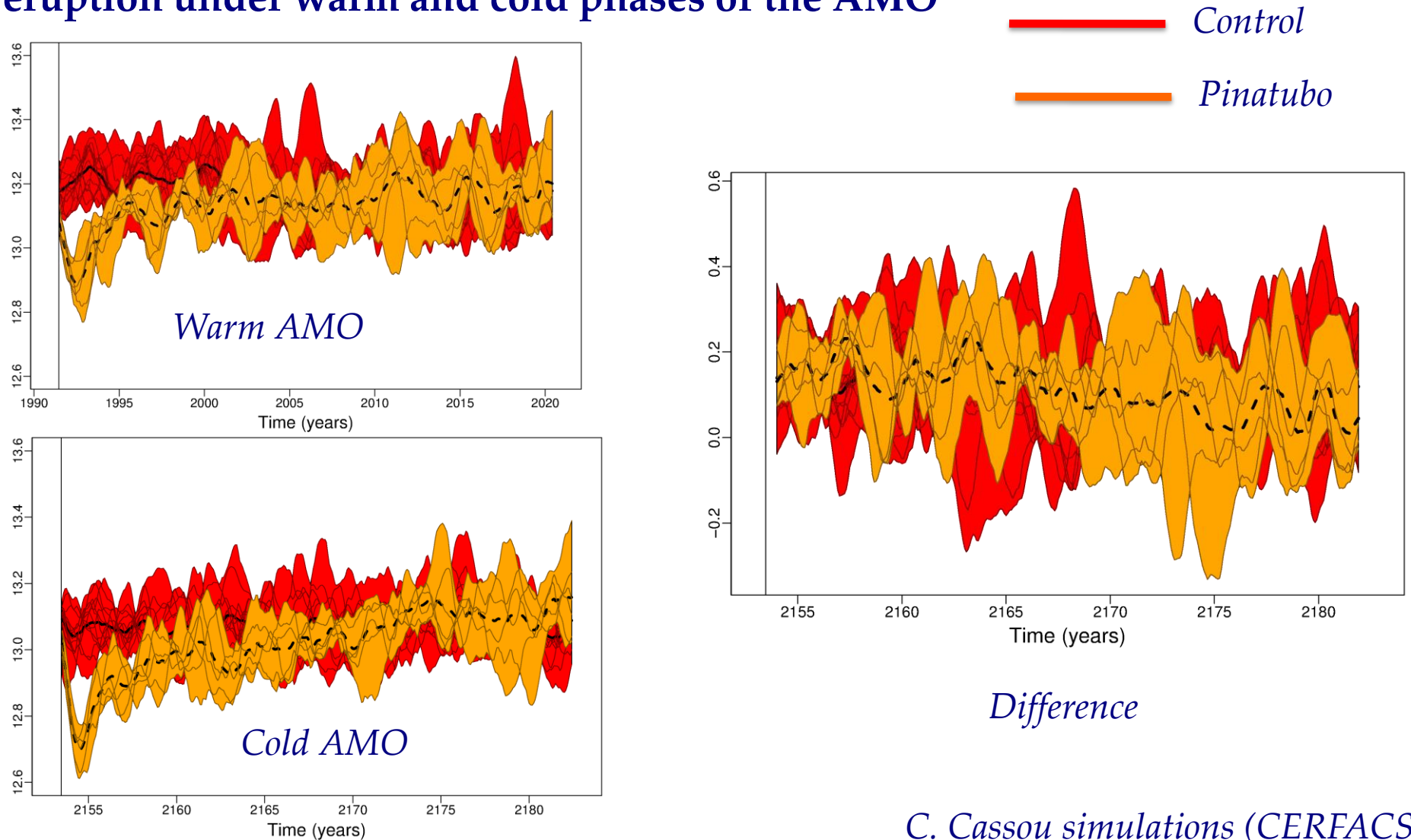
(With mixed  
climatology only for  
the experiment  
without volcanoes)

- 
- Climate response to volcanoes
  - Forecasts, anomalies and skills
  - **Large eruptions and the AMO**
  - Conclusions



## AMO impact on climate response to volcanoes?

→ “Perfect model experiments” with CNRM-CM5 simulating a Pinatubo eruption under warm and cold phases of the AMO

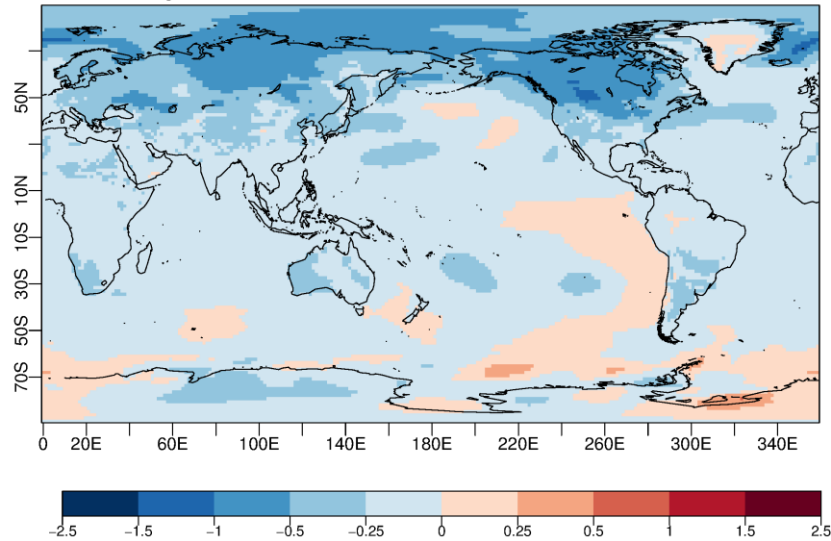




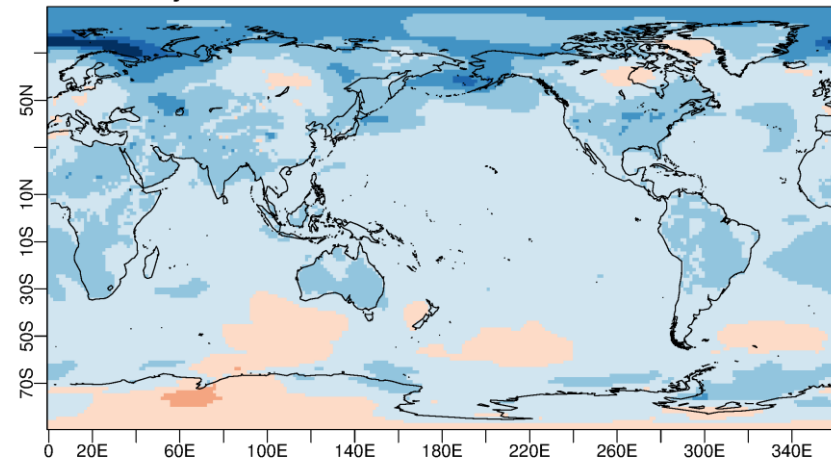
## AMO impact on climate response to volcanoes?

→ “Perfect model experiments” with CNRM-CM5 simulating a Pinatubo eruption under warm and cold phases of the AMO

5 years annual mean T ano after Pinatubo 1991

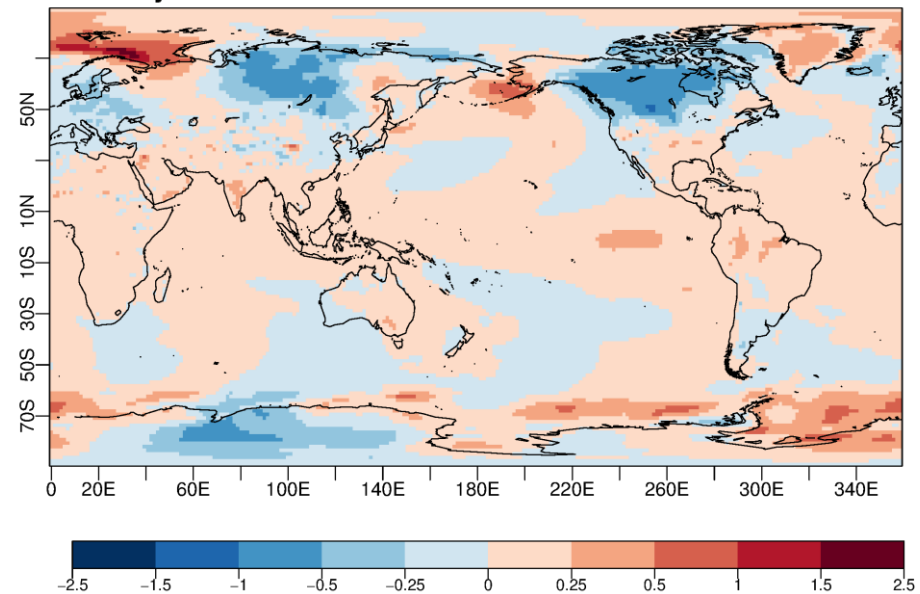


5 years annual mean T ano after Pinatubo 2153



*Warm AMO*

5 years annual mean T ano diff Pinatubo 1991–2153




*Difference*

*Cold AMO*

*C. Cassou simulations (CERFACS)*



- 
- Climate response to volcanoes
  - Forecasts, anomalies and skills
  - Large eruptions and the AMO
  - **Conclusions**



## Conclusions

---

- Large eruptions cool the climate, but the signal is difficult to understand, to simulate and to forecast because of the high natural variability.
- Which climatology has to be used to compute the anomalies?
- Small increase of the skills related to AMO/AMOC when adding volcanic forcing in forecasts.
- The AMO does not impact the global temperature response to large eruptions. The difference in regional response need to be more investigated.

### *Next step:*

- To investigate further these preliminary results.
- New experiments using idealized volcanoes forcing for real-time forecasts
- Testing stratospheric background levels changes based on recent observations

Thank you





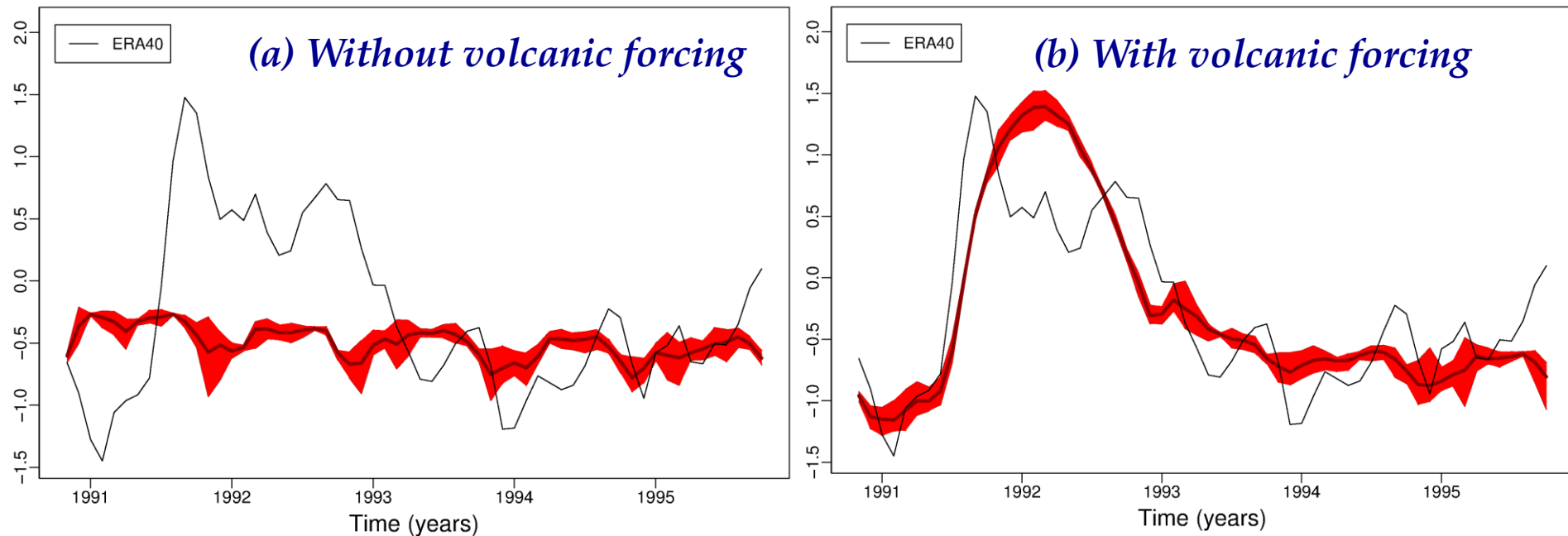
# Appendix



## EC-Earth experiments

→ CMIP5 Decadal hindcasts

→ Decadal hindcasts, years with eruptions without volcanic forcing



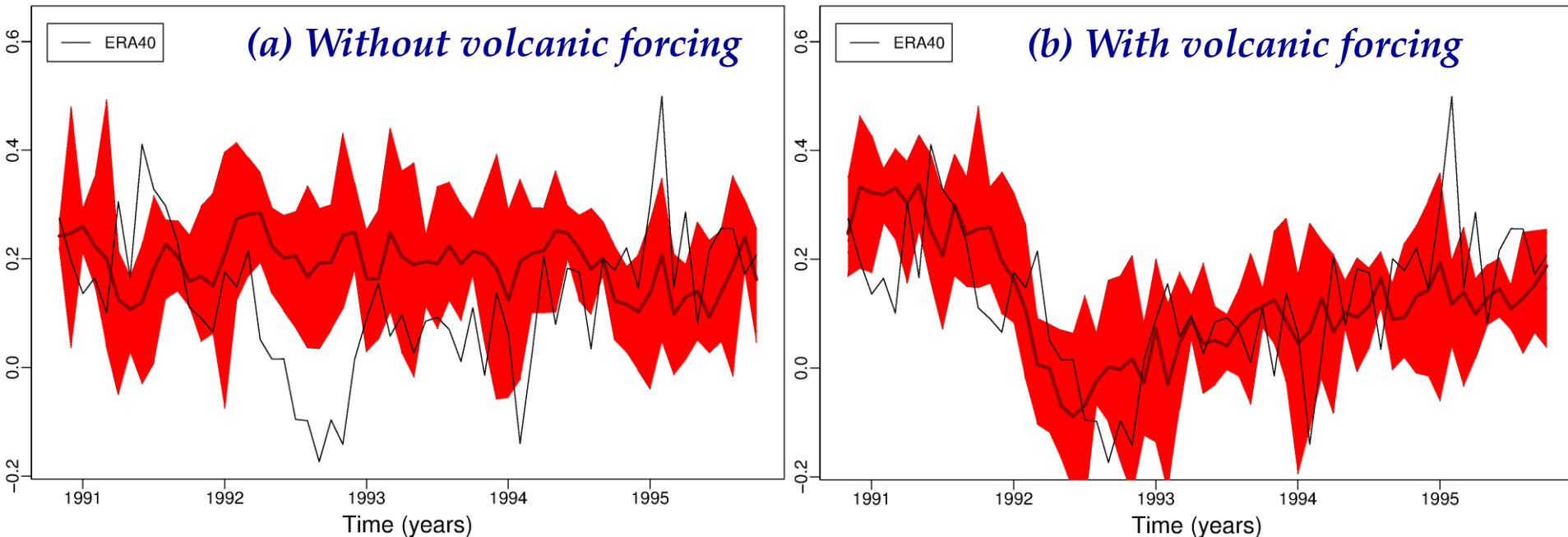
*Stratospheric temperature anomaly after Pinatubo eruption in EC-Earth simulations*



## EC-Earth experiments

→ CMIP5 Decadal hindcasts

→ Decadal hindcasts, years with eruptions without volcanic forcing

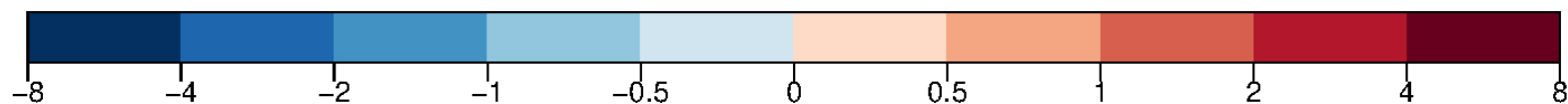


*Tropospheric temperature anomaly after Pinatubo eruption in EC-Earth simulations*

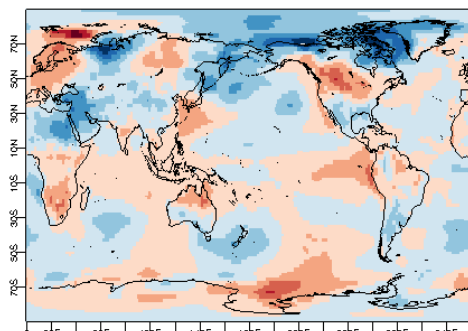




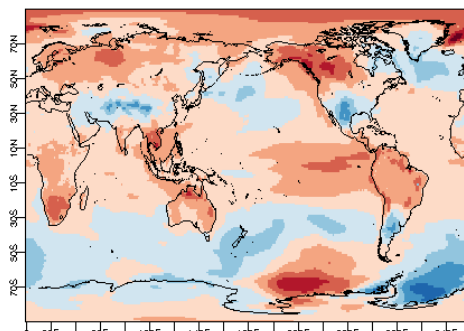
## Modelled climate response to volcanoes: temperature anomalies ( $^{\circ}\text{C}$ )



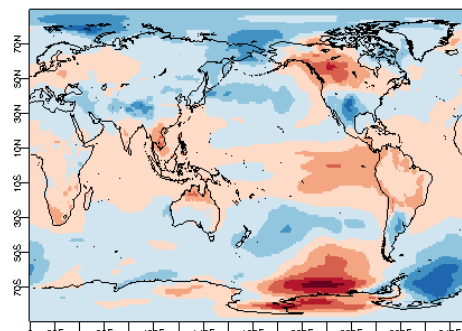
Year1



obs

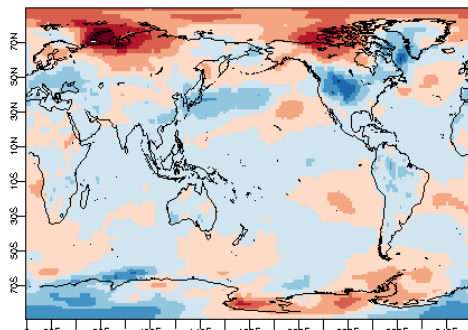


only initialization

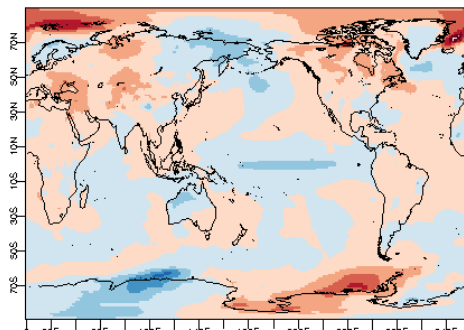


initialisation and volcanoes forcing

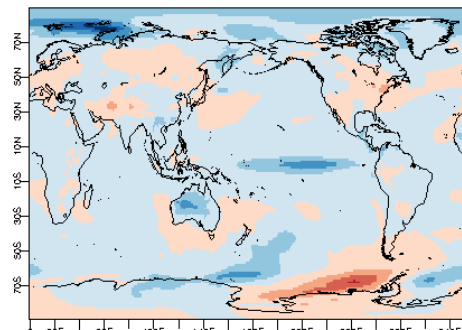
Year2



obs



only initialization



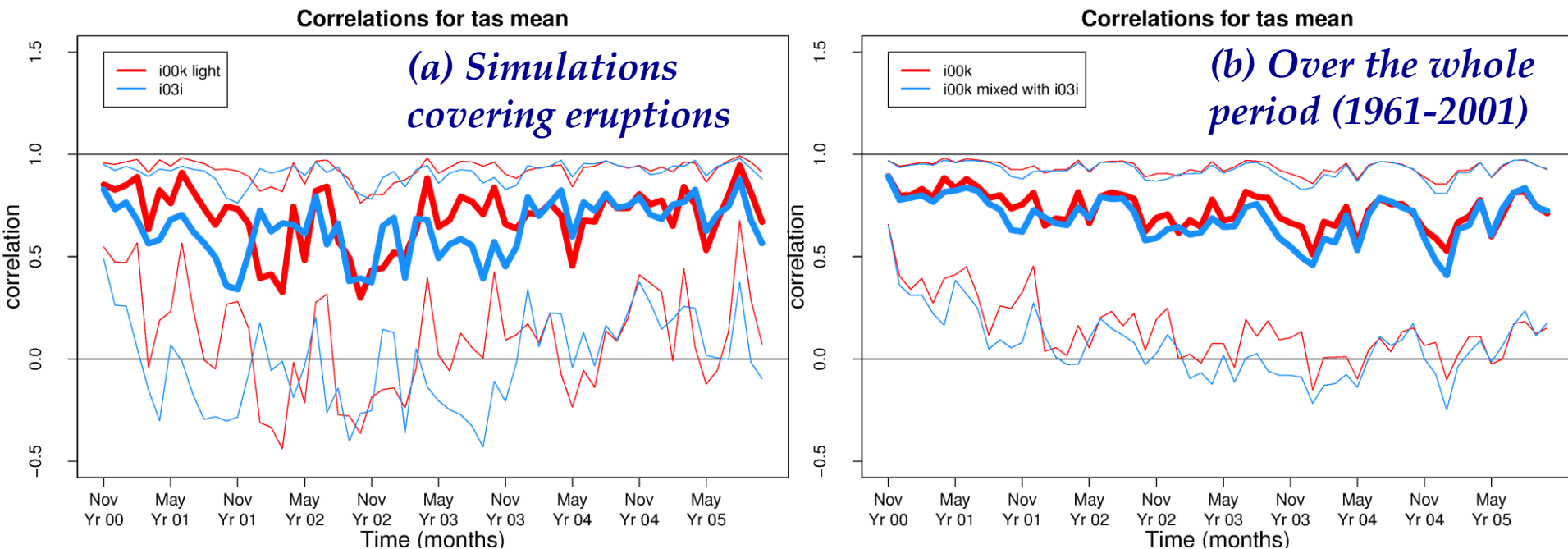
initialisation and volcanoes forcing

→ 1 observation versus (5 members x 3 startdates = 15) simulations

→ Volcanic signal => significant cooling, but partly masked by ENSO !



# Skills



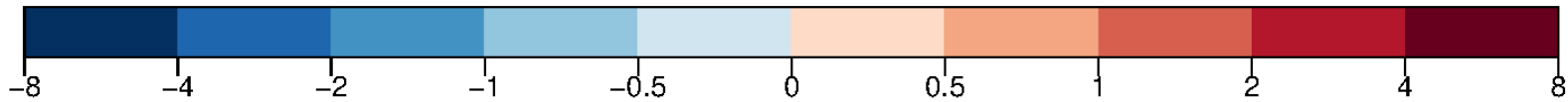
Without volcanoes

With volcanoes

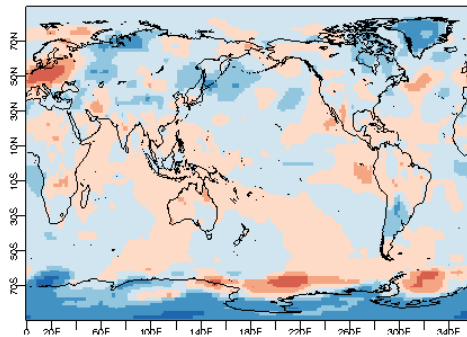
- Increase of TAS correlation when adding volcanic forcing for years 1 and 3
- Limited skill increase when computing it over all the startdates (1961-2001)



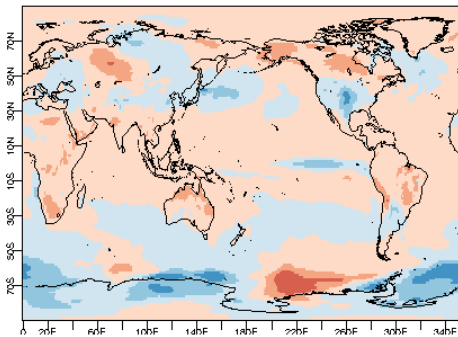
## Modelled climate response to volcanoes: surface temperature ( $^{\circ}$ C)



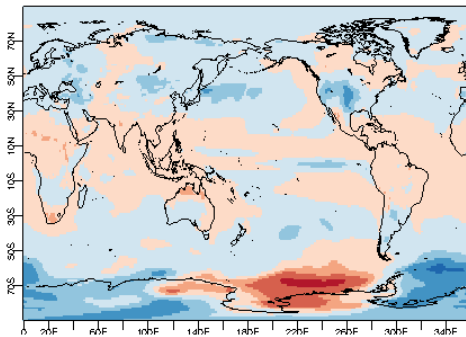
*JJA 1*



obs

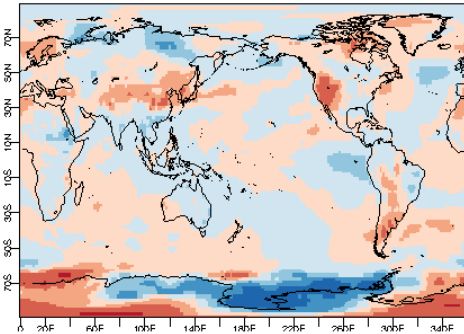


only initialization

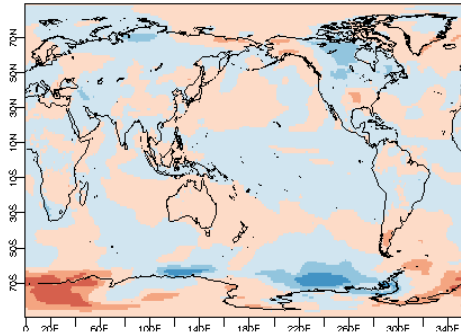


initialisation and volcanoes forcing

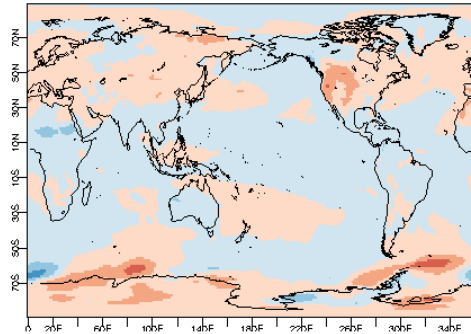
*JJA 3*



obs



only initialization

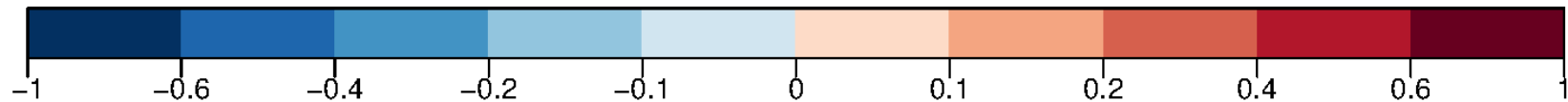


initialisation and volcanoes forcing

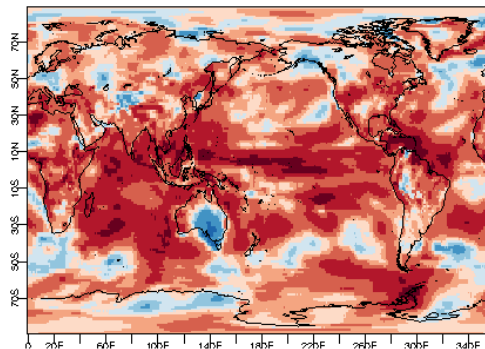
- General cooling better simulated with volcanic forcing during JJA 1
- Warming in some NH continental areas with volcanic forcing during JJA 3



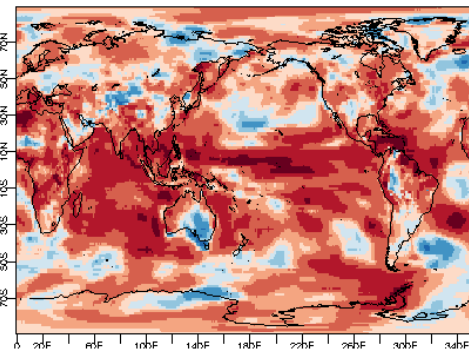
## Skills for surface temperature



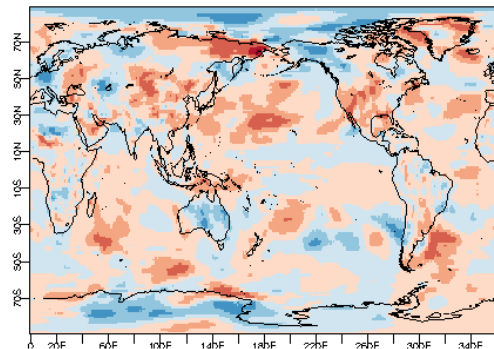
*JJA 1*



all forcings

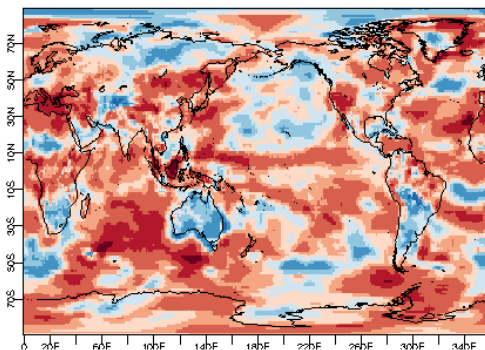


without volcanoes

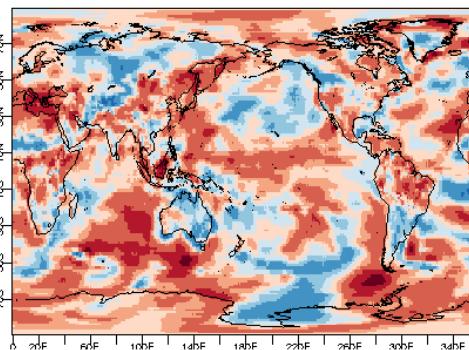


additional cor with volcanoes

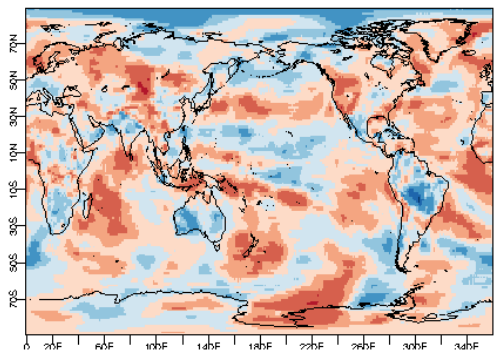
*JJA 3*



all forcings



without volcanoes



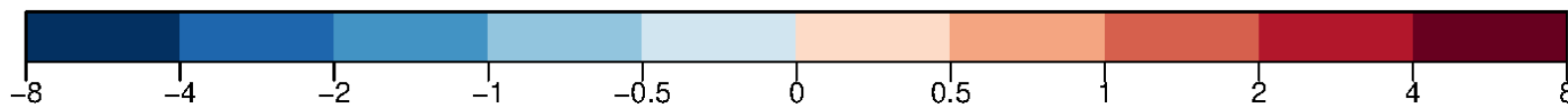
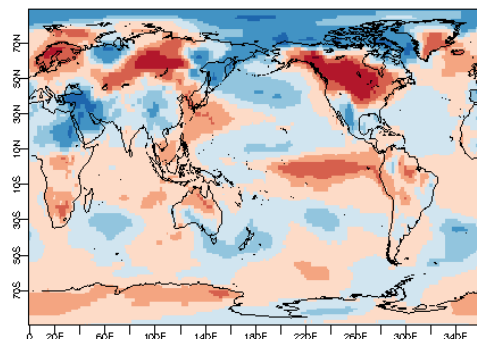
additional cor with volcanoes

→ General increase of correlation during JJA, significant but noisy

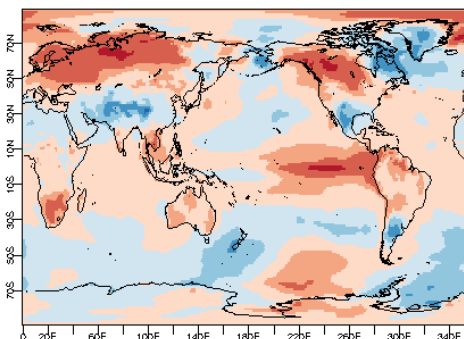


# Modelled climate response to volcanoes (surface temperature anomalies)

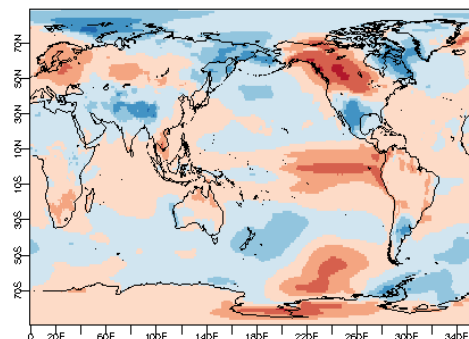
°C

*DJF 1*

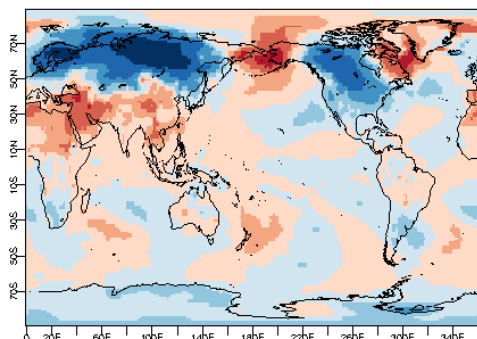
obs



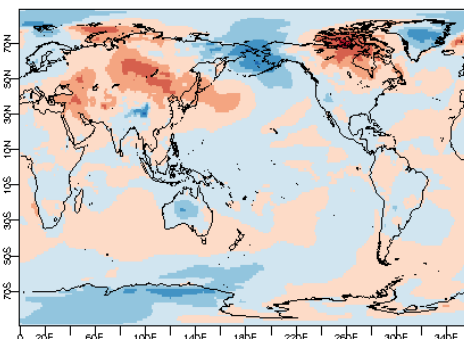
only initialization



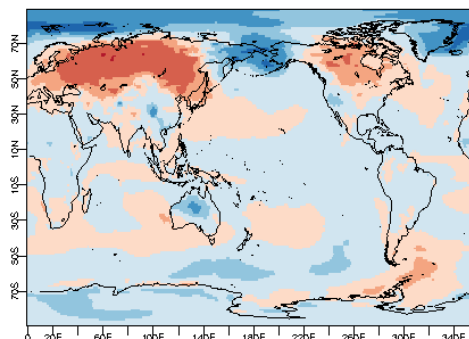
initialisation and volcanoes forcing

*DJF 3*

obs



only initialization



initialisation and volcanoes forcing

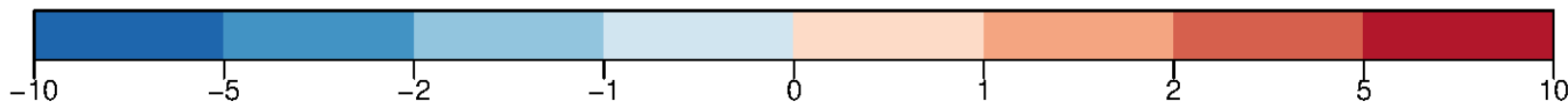
→ General cooling better simulated with volcanic forcing in NH winter 1

→ Potential winter dynamical response in NH?

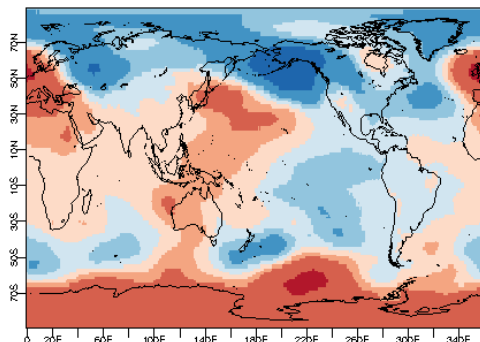




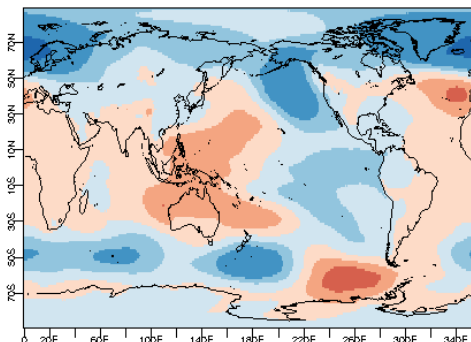
## Modelled climate response to volcanoes (Sea level pressure anomalies hPa)



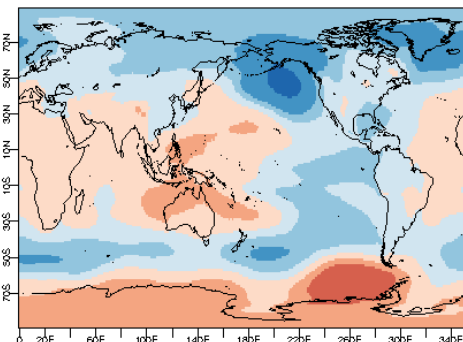
*DJF 1*



obs

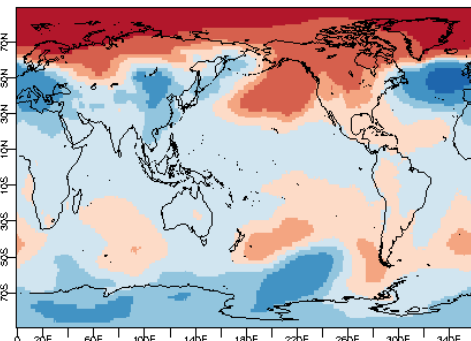


only initialization

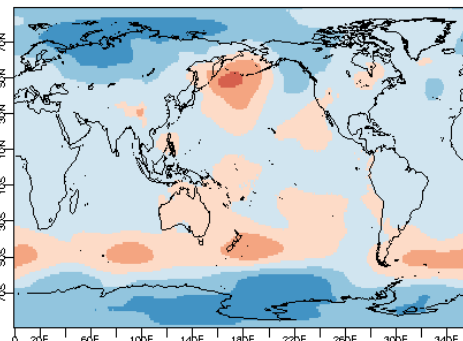


initialisation and volcanoes forcing

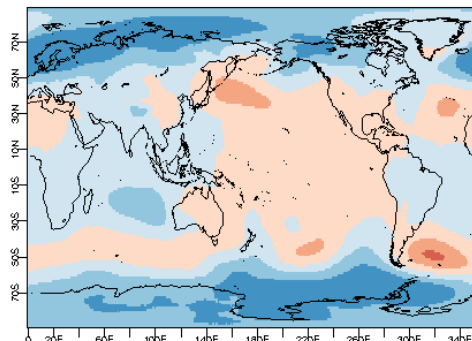
*DJF 3*



obs



only initialization



initialisation and volcanoes forcing

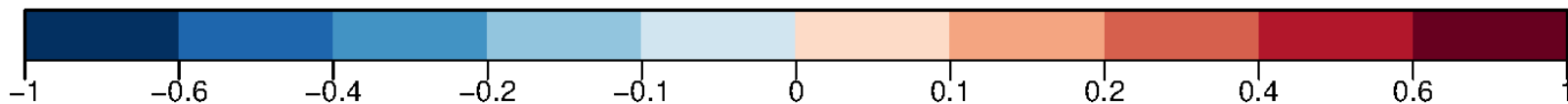
→ SLP increase in SH better simulated with volcanic forcing during DJF 1

→ Potential winter dynamical response in NH difficult to catch with models

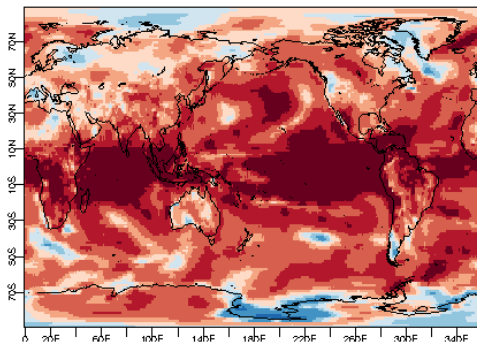




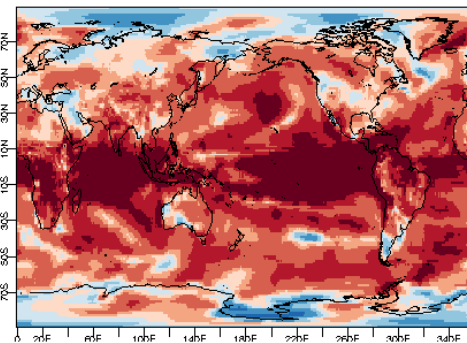
## Skills for surface temperature



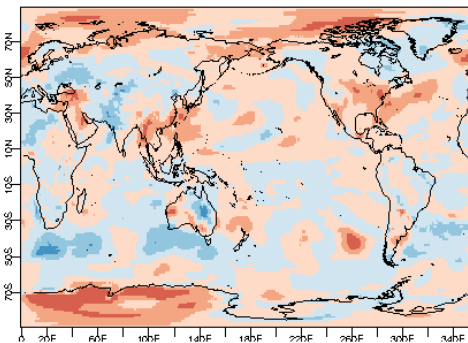
*DJF 1*



all forcings

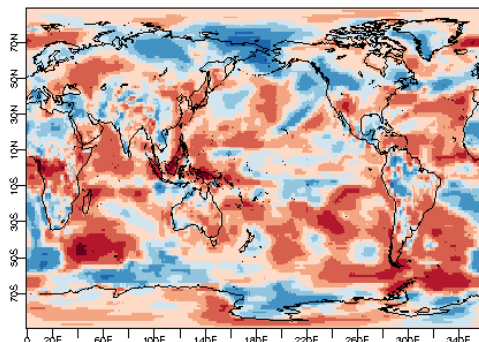


without volcanoes

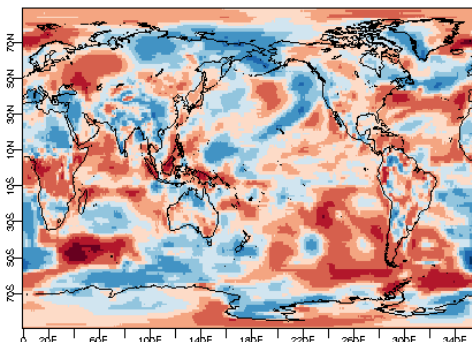


additional cor with volcanoes

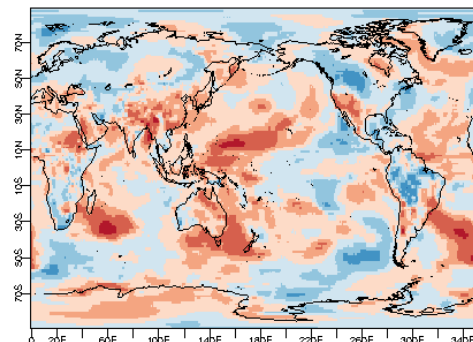
*DJF 3*



all forcings



without volcanoes



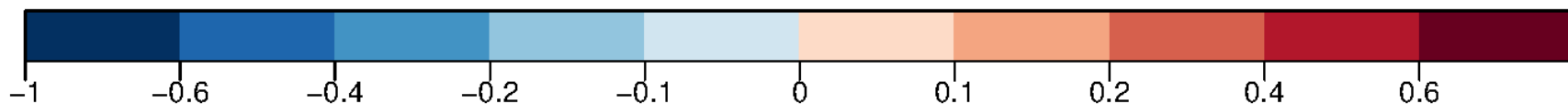
additional cor with volcanoes

→ Significant increase of correlation at high latitudes during DJF 1

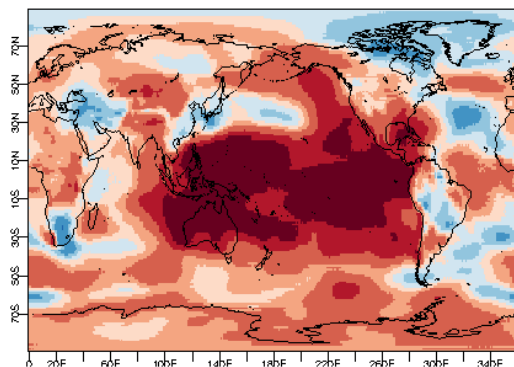
→ Skill increase in the tropics in DJF 3



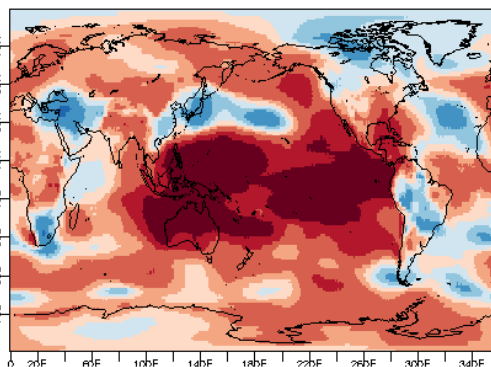
## Skills for surface pressure



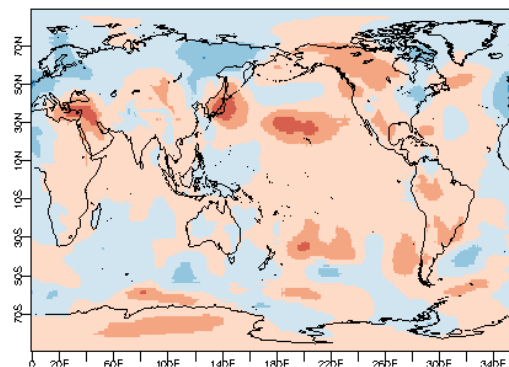
*DJF 1*



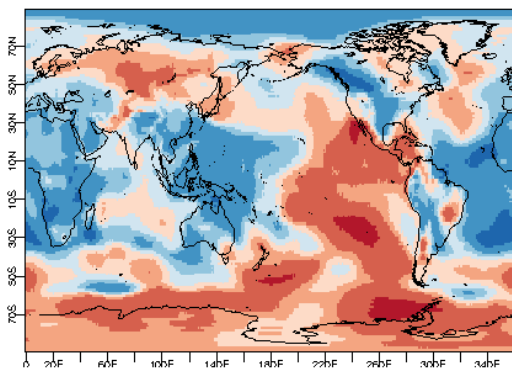
all forcings



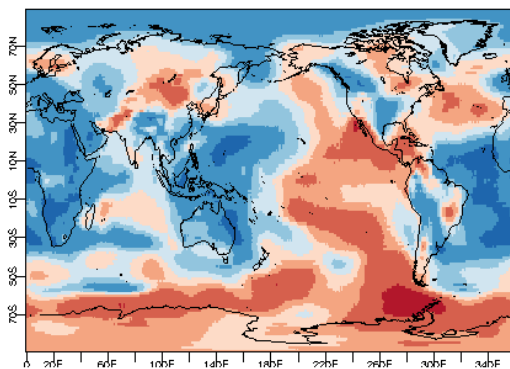
*DJF 3*



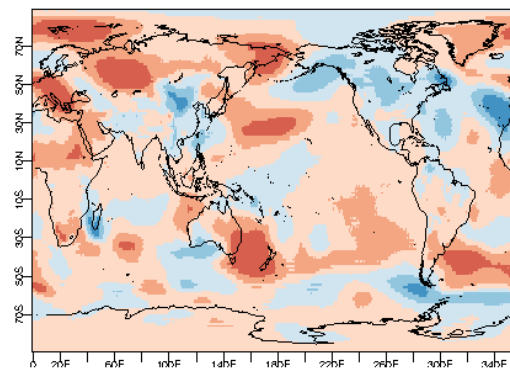
additional cor with volcanoes



all forcings



without volcanoes



additional cor with volcanoes

→ Increase of correlation during DJF 3, more pronounced than for DJF 1, and especially marked for middle to high latitudes



## Conclusions

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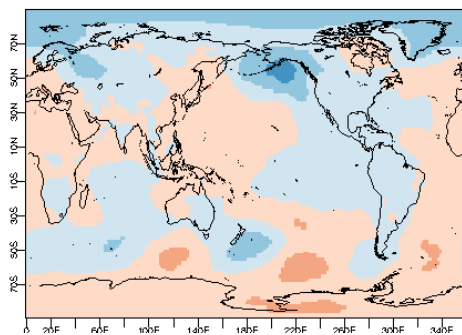
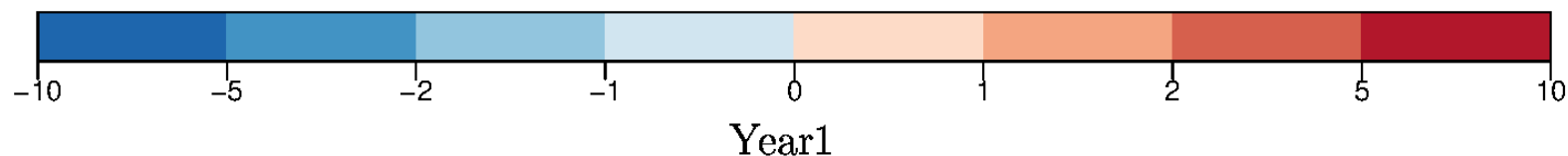
- Increase of skills related to volcanoes forcing in years 1 and 3 in EC-Earth simulations
- Increase explained by the significant general cooling of the atmosphere that follows an eruption (radiative forcing).
- It is challenging to understand the dynamical response with the limited number of observations; it is also tricky to simulate it with models.

### *Next step:*

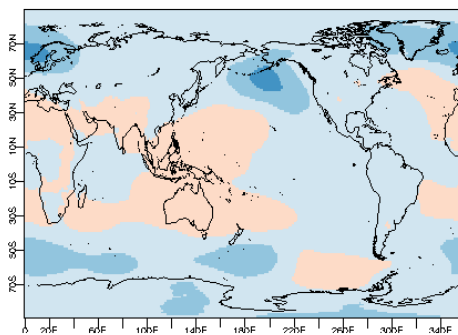
- New experiments using idealized volcanoes forcing for real-time forecasts
- Testing stratospheric background levels changes based on recent observations



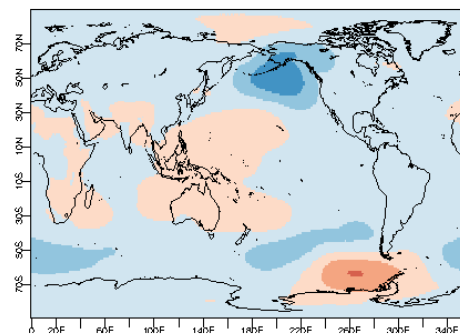
## Modelled climate response to volcanoes: pressure anomalies



obs

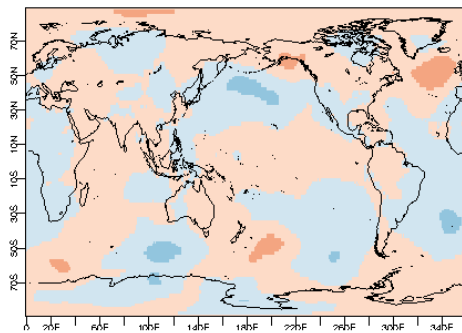


only initialization

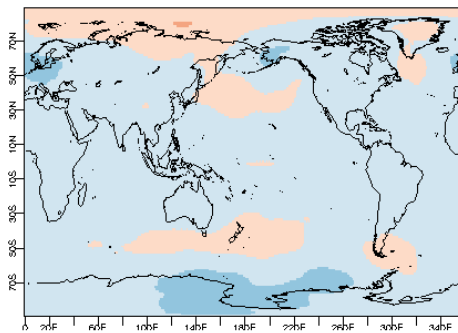


initialisation and volcanoes forcing

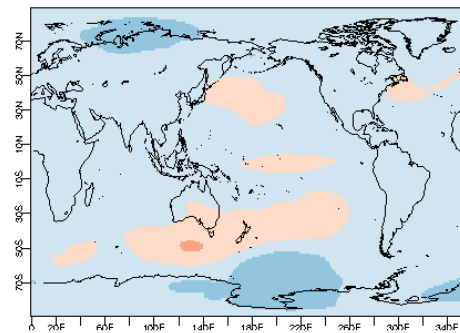
Year2



obs



only initialization



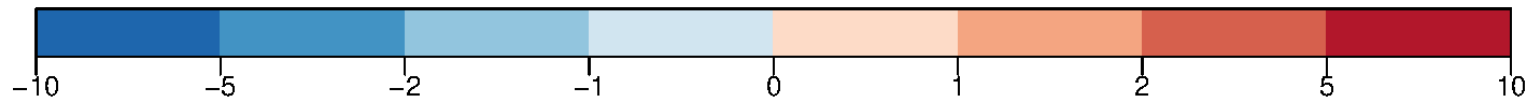
initialisation and volcanoes forcing

→ 1 observation versus (5 members x 3 startdates = 15) simulations

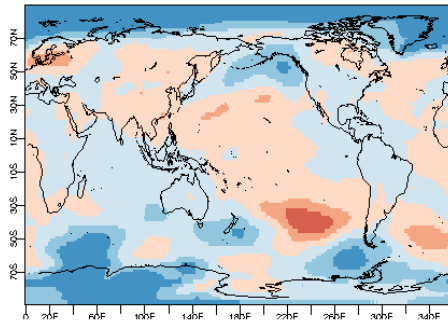
→ No significant signal of volcanoes on sea level response at yearly scale



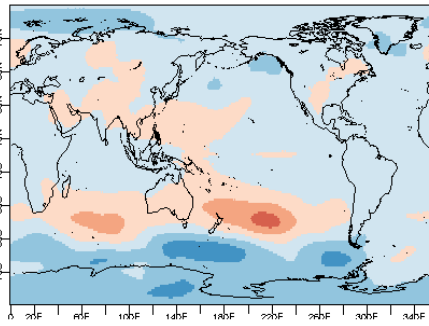
## Modelled climate response to volcanoes: sea level pressure (hPa)



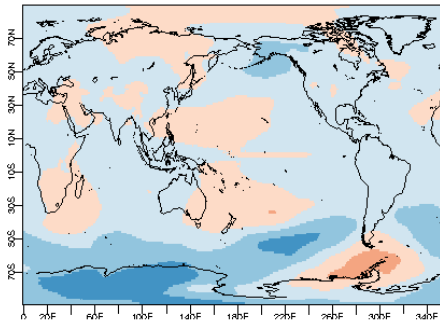
*JJA 1*



obs

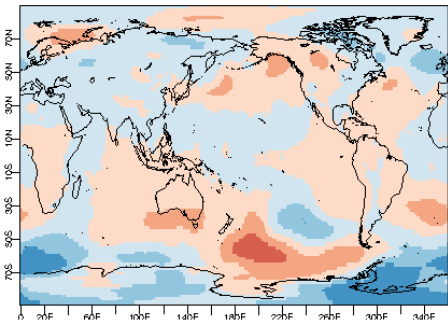


only initialization

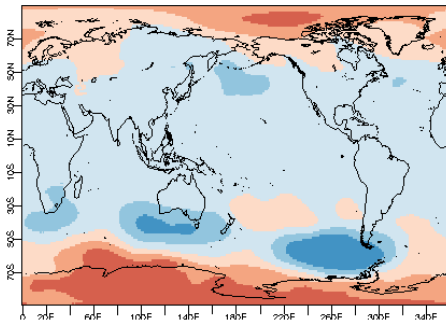


initialisation and volcanoes forcing

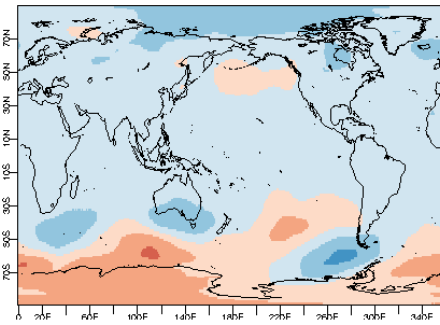
*JJA 3*



obs



only initialization



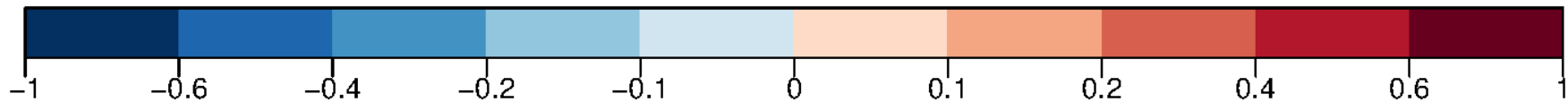
initialisation and volcanoes forcing

→ SLP response to volcanoes during austral winter ?

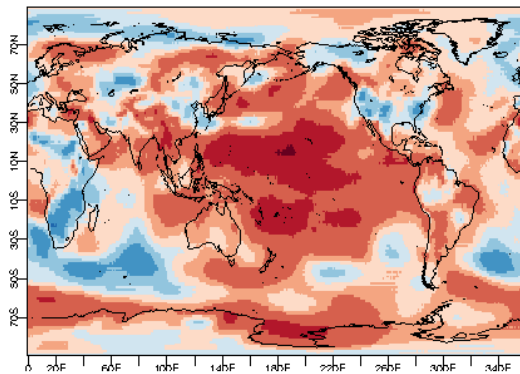




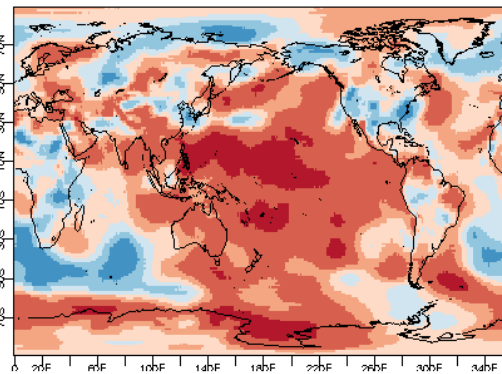
## Skills for sea level pressure



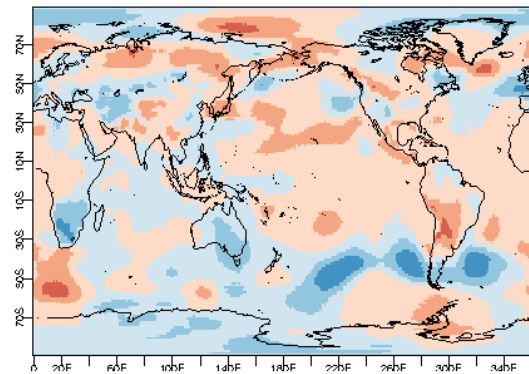
*JJA 1*



all forcings

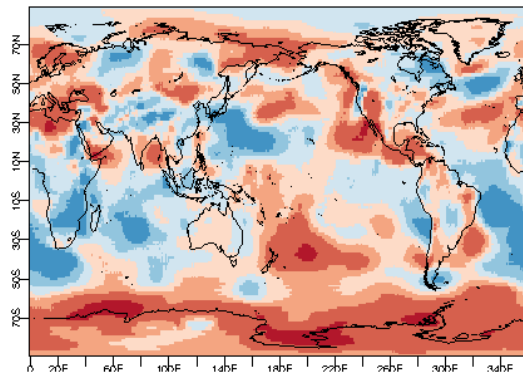


without volcanoes

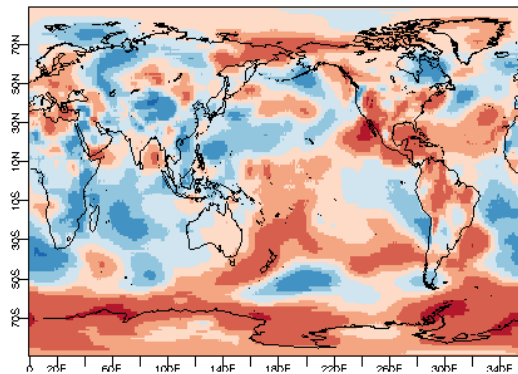


additional cor with volcanoes

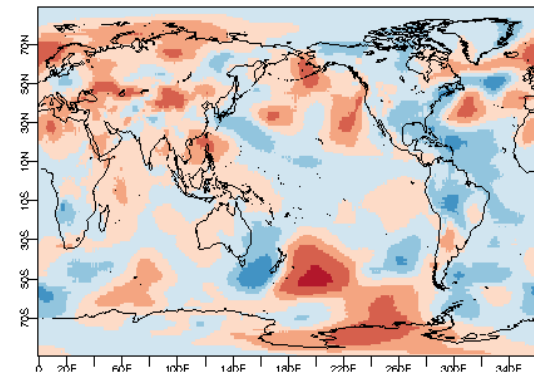
*JJA 3*



all forcings



without volcanoes



additional cor with volcanoes

→ General increase of correlation during JJA, significant but noisy





## Appendix

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→ precipitation, Z500 and SLP analysis

→ comments of Paco:

Linear trend not excluded when computing skills

Cross-validation for volcanoes anomalies?